1969

Total corn harvesting: machine design and system analysis

Thomas E. Hitzhusen
Iowa State University

TOTAL CORN HARVESTING:

MACHINE DESIGN AND SYSTEM ANALYSIS

by

Thomas E Hitzhusen

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

MASTER OF SCIENCE

Major Subject: Agricultural Engineering

Approved:

____
In Charge of Major Work

____
Head of Major Department

____
Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1969

TABLE OF CONTENTS

INTRODUCTION

Changes in regional beef production patterns are redefining the role the midwestern states will assume in the future agricultural complex. Historically, beef production in the Midwest consisted primarily of fattening calves produced in the range areas of the central and western states; however, in the past ten years that pattern has been altered abruptly (32). From 1958 to 1968, production of fat cattle more than doubled in the western states and nearly tripled in the central states. By 1968, these two regions contributed 60 percent of the fat cattle marketed in the U.S. (49, 56). During this same period, the western states increased their beef cow numbers by 32 percent while beef cows in the central states increased by 49 percent, and by 1968 these two areas accounted for 60 percent of the beef cows in the U.S. With their feed grains produced under irrigation, these western and central states are now feeding almost as many cattle as they raise with the result that the Midwest is losing its sources of feeder cattle (32). Figure 1 defines the regional production areas and Figures 2 and 3 illustrate the distribution of fed cattle and beef cows in the U.S.

While the Midwest is losing its supply of feeder cattle, the total demand for beef has increased rapidly due to both an increased population and increased beef consumption per capita. From 1956 to 1968, the population of the U.S. increased by 20 percent (168.6 to 201.6 million) and the consumption per capita increased by another 19 percent (94.9 to 113.1 pounds per person) resulting in a 43 percent increase in total beef consumption (60). Expenditures for beef now

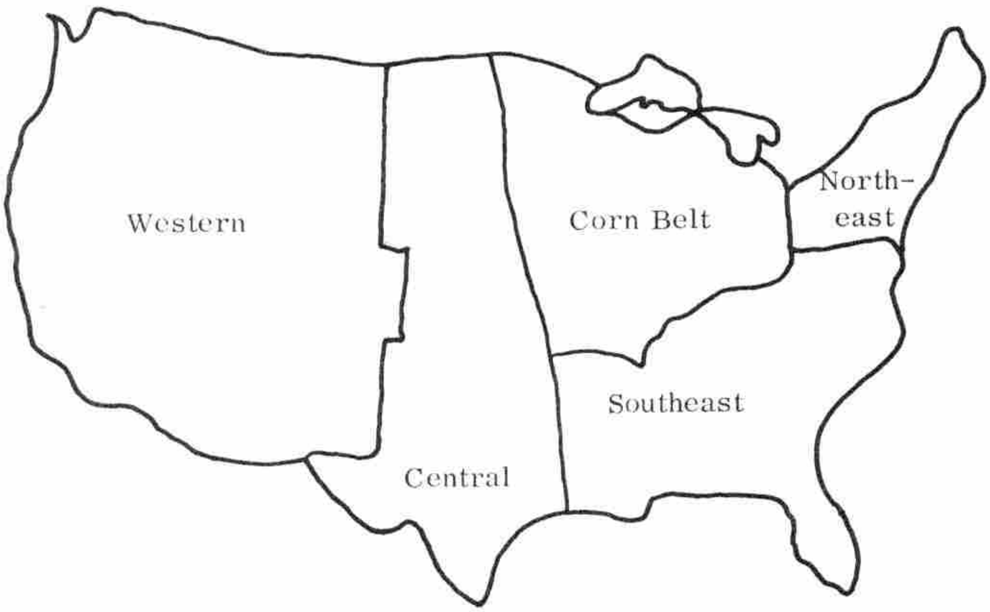


Figure 1. U.S. regional divisions

Western	Central	Corn Belt	Southeast
Washington	North Dakota	Minnesota	West Virginia
Oregon	South Dakota	Iowa	Virginia
California	Nebraska	Missouri	North Carolina
Nevada	Kansas	Wisconsin	South Carolina
Idaho	Oklahoma	Illinois	Kentucky
Montana	Texas	Michigan	Tennessee
Wyoming		Indiana	Arkansas
Utah		Ohio	Louisiana
Colorado			Mississippi
Arizona			Alabama
New Mexico			Georgia
			Florida

Table 1. Number of fed cattle marketed, millions, and percentage contribution from regions to U. S. total for selected years

Region	1955	%	1958	%	1968	%
Western	2.1	23.1	2.8	24.5	5.8	25.3
Central	2.5	27.5	2.8	24.5	7.9	34.5
Corn Belt	4.5	49.4	5.6	50.1	8.6	37.6
Northeast and Southeast	---	--	0.1	0.9	0.6	2.6
Total	9.1		11.2		22.9	

Table 2. Number of beef cows, millions, and percentage contribution from regions to U. S. total for selected years

Region	1949	%	1958	%	1968	%
Western	4.5	28.5	5.7	23.5	7.5	21.4
Central	6.9	43.7	9.1	37.6	13.5	38.6
Corn Belt	1.9	12.0	3.6	14.9	5.5	15.7
Northeast and Southeast	2.5	15.8	5.8	24.0	8.5	24.3
Total	15.8		24.2		35.0	

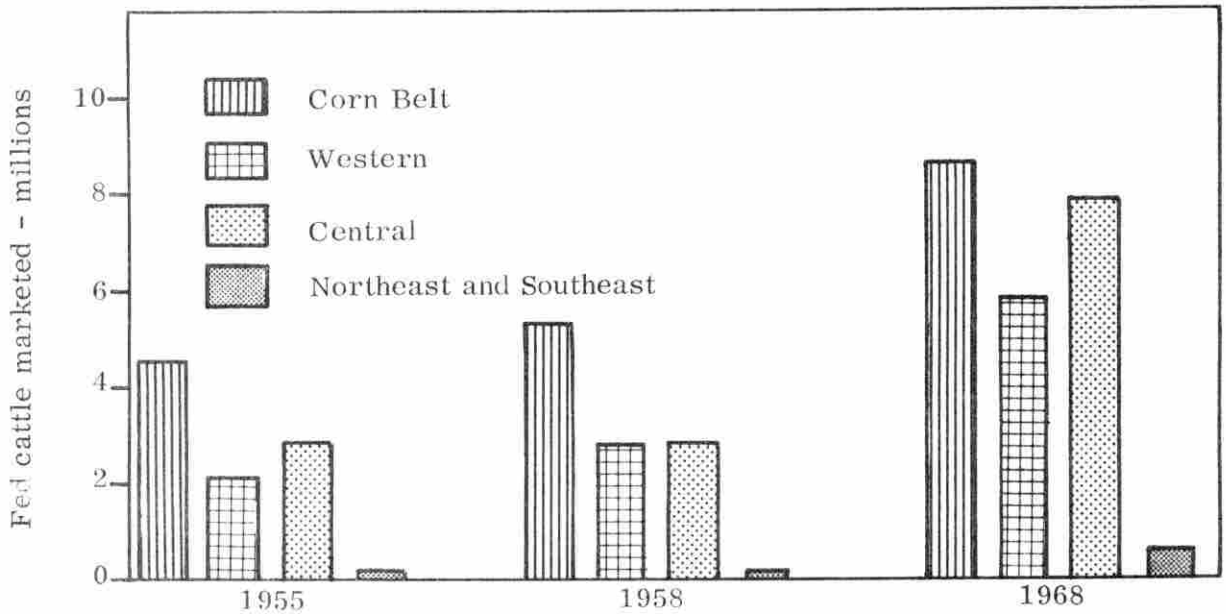


Figure 2. Fed cattle marketed by regions

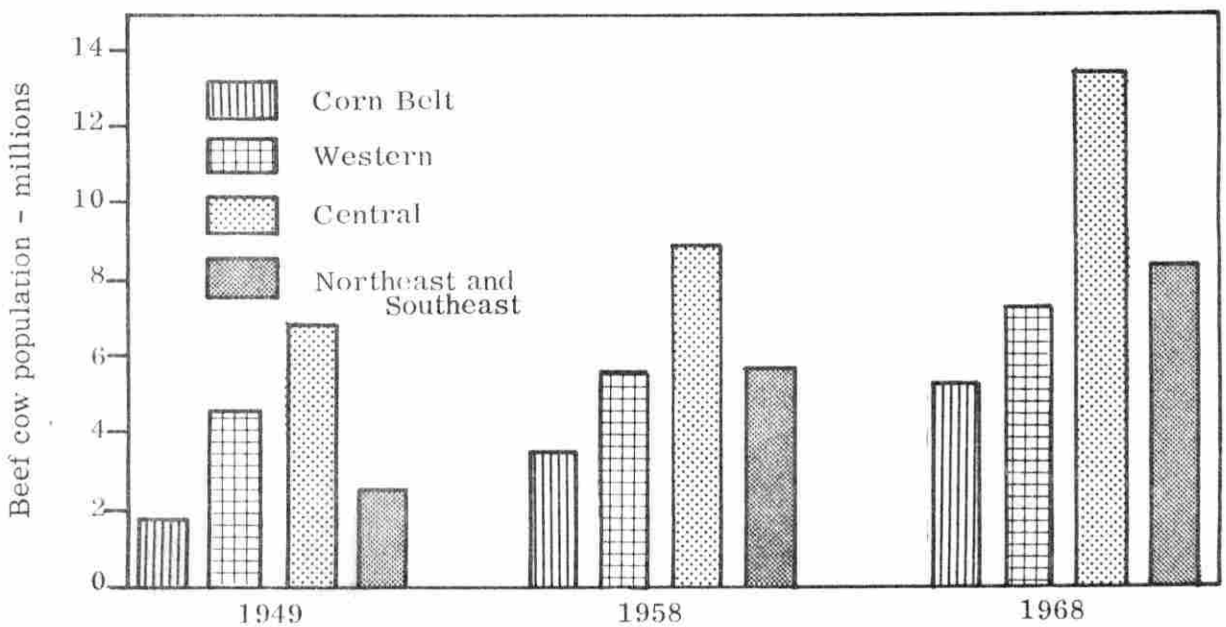


Figure 3. Beef cow population by regions

account for approximately 14 percent of the average family food budget (60). Researchers are projecting that consumer demand for beef will continue to increase, precipitating even greater rates of increase in beef production in future years.

This increased demand for beef can be satisfied in part by the utilization of the abundant feed resources in the Midwest. This area produces a surplus of feed grains plus a surplus of corn stalk residue. Feeding trials indicate that corn refuse makes a satisfactory beef cow maintenance ration when properly supplemented (1, 6, 7, 10, 34, 61).

Meiske and Goodrich (34) state, "Because of increased buying competition from the West and Southwest, the Corn Belt may need to produce an increasing proportion of its feeder cattle supply. It seems reasonable that the Corn Belt should more completely utilize 'low quality' forages and by-products such as cornstalks and corn cobs. The beef cow is the animal of choice to utilize these forages."

Yaw (64) suggests that "feed supplies for cows should come primarily from feedstuffs otherwise wasted such as cornstalks, from rough land unsuited for row crops, and from farm program land that can be grazed after deadlines."

Cornstalk residue is available from over 55 million acres in the United States annually (21). This represents approximately 86.7 percent of the total corn acreage with the balance being harvested for silage or forage. In Iowa alone, 9.7 million acres of residue are available from the 10.2 million acres of corn produced.

This vast potential source of feed has been neglected in the past for several reasons. The grain is the easiest part of the corn plant to harvest and handle, plus it contains half of the total plant dry matter and 60 to 70 percent of the nutrients and energy (14). Harvesting machinery has been developed to collect the grain, but little has been done to develop machinery for harvesting the corn plant residue. Also, the corn belt states have always obtained an adequate supply of feeder calves from the western states and have not been forced to produce their own with indigenous cow herds (24).

Present beef production and shipping levels result in a deficit of feeder calves in the Midwest. Iowa alone imports 2.5 million head of feeder calves annually (24). In order to erase this deficit, an increased number of beef cows will need to be maintained either by increasing the acreages of pasture or by utilizing the corn stalk residue.

The feasibility of maintaining beef cow herds in the Midwest on corn stalk residue depends in part on the development of efficient and economical machinery to harvest, handle and feed refuse ensilage. In the late 1940s, Rosenthal and Case offered field machines to collect ear corn and stover ensilage, but they were confronted with problems of handling and storing high moisture corn, high power requirements, low field capacity, and the fact that additional beef cow herds were not needed in the Midwest at that time.

Total corn harvesting seems more feasible now than it did 20 years ago for several reasons. The technology and equipment are now available to either store high moisture shelled corn in a gas-tight silo or dry it artificially. The lack of power is not so restrictive now since big tractors are common and power is relatively cheap. Changes in the price-cost relationships have forced farmers into a more competitive position which requires them to obtain a higher return from each land unit.

In 1965, Iowa State University initiated a program to develop a machine to harvest both high moisture shelled corn and refuse ensilage with one machine in one operation. The first successful machine arising from that program was built by Ferlemann (13) and modified by Schroeder (41) and was labeled the Beefmaker I. That machine consisted of a modified forage harvester mounted on a conventional combine between the threshing cylinder and the cutoff head. Capacity was limited, but it did produce an acceptable product and was considered to be a feasible system for some farmers.

The search for other feasible systems continued, and in the summer and fall of 1968 another total corn harvester was designed and built. That machine utilized a conventional forage harvester as the basic machine, and a snapping attachment was mounted between the row crop head and the cylinder cutter head. A cage sheller was added to provide the options of collecting shelled corn and refuse ensilage or ear corn and stover ensilage, and by removing the snapping-shelling attachment, the machine could be used to harvest whole plant ensilage. Field tests were conducted in the fall of 1968 to evaluate functional performance and field losses. In further discussion in this thesis, this machine is referred to as the Beefmaker II.

Research was also conducted on other aspects of interest in a total corn harvesting system. Feeding trials were continued to evaluate the refuse ensilage in terms of palatability and required supplementation to maintain a beef cow. The Animal Science Department at Iowa State University conducted the actual feeding trials, but the Agricultural Engineering Department was responsible for harvesting and processing the refuse ensilage.

In order to evaluate different corn hybrids for suitability in a total harvesting system, the relationship between the moisture content of the kernel and the refuse was investigated. These data were necessary to estimate the length of time available for total harvesting for each hybrid and thus to predict the required field capacity and labor needed.

A system analysis was conducted for a model midwestern farm involved in a total harvesting system. Linear programming techniques were employed to optimize net farm income given various forage and feeding options. The beef cow-calf enterprise was forced to compete with other production functions common to a midwestern farm.

Future predicted demands for beef, coupled with the shifts in regional production levels, indicate that the midwestern states will need to maintain more beef cows in the future. Slight changes in price-cost relationships and the development of a total corn harvesting machinery could make the cow-calf herd a very competitive enterprise for this area, and could significantly influence the nature of midwestern farming.

OBJECTIVES

The objectives of this research endeavor were:

1. To conduct a system analysis of a total corn harvesting system.
2. To design, construct, and test a total corn harvester.
3. To determine the relationship between kernel moisture content and refuse moisture content for several varieties of corn.

TERMINOLOGY

Total corn harvesting:	The concept of utilizing the entire corn plant. It involves gathering the corn plant and removing the grain from the stalk.
Whole plant corn ensilage:	The sum of the corn plant parts less the roots.
Corn stover:	The sum of the corn plant parts less the roots, cob, and kernel.
Corn refuse:	The sum of the corn plant parts less the roots and kernel. Corn stover plus the cob.
Beefmaker I:	An Iowa State University experimental total corn harvester consisting of a modified forage chopper mounted on a combine.
Beefmaker II:	An Iowa State University experimental total corn harvester consisting of a snapping-shelling attachment mounted on a forage chopper.

LITERATURE REVIEW

Total Corn Harvesting Machinery

The evolution of a new machine has always been a long and deliberate process. This has been especially true for agricultural machinery where climatic and biological factors contribute uncertainty to an already complicated problem. The plant-machine interface has presented formidable problems which have confronted engineers and scientists since the beginning of the agricultural mechanization effort[1]. Plant properties have influenced the development of agricultural machinery to such an extent that farmers have changed their methods of cultivation in order to better utilize available machinery. This was especially true in the case of corn production. Colonial farmers harvested corn by hand and utilized the entire corn plant, but mechanization of whole plant harvesting presented some technical and material handling problems which delayed that method of harvesting for almost 80 years. In the meantime, the corn stalks were sacrificed for the adoption of grain harvesting machinery which was easier and quicker to develop (67).

The first corn harvesting machines to be built were total corn harvesters. This was logical because prior to 1820, when the corn crop was harvested

---

[1]Buchele, W. F., Ames, Iowa, Iowa State University of Science and Technology Agricultural Engineering Department. The concept of total corn harvesting. Private communication. 1968.

entirely by hand, the whole plant was utilized, so when the first machines were designed, they did not depart from the cultural practices of the day.

In 1866, Enfield (11) stated that "The stover of Indian corn, slighted as it too often is, has come to be a large and valuable item in American husbandry. Its nutritive value for feeding purposes, and the amount yielded per acre, render it intrinsically and practically an important crop."

The pioneer farmers prior to 1900 practiced total harvesting because they were forced by the lack of labor and machinery to fully utilize each acre of corn which had been so laboriously cultivated. They cut the stalks just above the ground by hand and transported them to the farm yard. During the winter months the ears were removed by hand and the stalks were either used for bedding or feed (11).

Since the colonial farmers were accustomed to utilizing the entire corn plant, the first machines to be designed were total harvesters. However, due to the lower power requirement, the lower labor requirement, and the reduced volume of material to be handled, the grain harvesting equipment was developed quicker and to a higher level of sophistication. Yet many of the early husbandrymen felt that their acceptance of grain harvesters was a compromise with the machinery developers and that the whole plant should be harvested as soon as the problems of mechanization were resolved. Zintheo (67) stated in 1907 that "The corn picker should be considered as a temporary machine for emergency use only until such a time as the American farmers will be able to utilize all of the food products grown on their farms."

Enfield (11), 1866, described the situation in even harsher words by explaining that the most enlightened cultivators were invariably careful in securing the whole of their stalk crop, and would no sooner leave a portion of it standing in the field than they would abandon a similar amount of any other crop they raise. Furthermore, he said no sane man would leave half of his stalk crop to perish in the field because the stalks accounted for one-third of the value of the crop.

The first corn harvester was patented by J. C. Peterson of West Mansfield, Ohio, in 1886. It consisted of a cutting edge mounted on a sled on which the operator rode and manually gathered the stalks as they were sheared. The sled type machine was faster than harvesting by hand, but it performed poorly in lodged corn and wet fields. Consequently, gathering arms were added, the sled was mounted on wheels, and two cutting edges were used to simultaneously harvest two rows (67). Figure 4 illustrates an early sled harvester.

The next machine to appear was similar to the sled harvester except it included a ground driven sickle which sheared the corn and deposited it horizontally on a platform. It also utilized lifting arms and gathering chains to improve the performance in lodged corn. Two men followed the machine and when enough corn had been cut to start a shock, they stopped the horse and tied the stalks with twine. This was very exhausting work, but two men and a horse could harvest four and one-half acres per day as compared to one and one-half acres per day per man by hand (67).

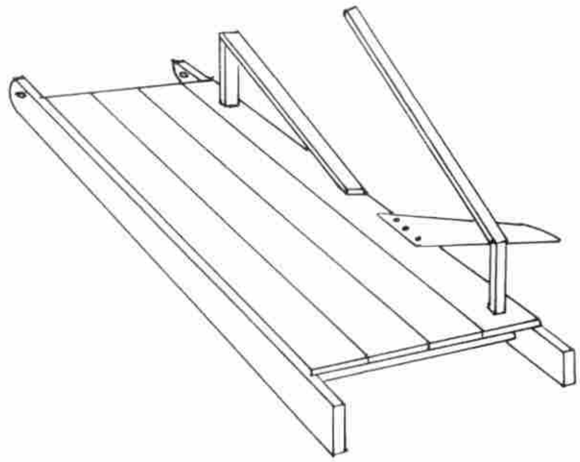


Figure 4. Sled harvester used to gather corn, 1886

Figure 5. Vertical corn binder patented by A. S. Peck, 1892

The next machine to gain popularity was the corn binder. The first corn binder patent was issued to A. S. Peck of Geneva, Illinois, in 1892 (67). This machine sheared the stalk with a sickle and carried it back in a vertical position by means of gathering chains. The stalks were collected, tied, and discharged on the ground without stopping. Since the horses pushed from behind, the Peck binder was more successful in lodged corn than any of the earlier machines. One man with three horses could harvest eight acres of corn per day with a binder. Figure 5 shows the Peck binder in operation.

A corn shocker was developed by A. N. Hadley about the same time Peck developed the binder. The shocker was very similar to the binder, but it also had a large revolving table behind the gathering head. The stalks were placed vertically on the revolving table until enough were collected to form a shock and then a crane with a rope and pulley arrangement was used to transfer the completed shock from the platform to the ground. The shocker and binder were used extensively from 1910 to 1946 to collect corn to fill silos with ensilage and to collect corn for processing with a husker-shredder.

All of the afore mentioned machines were used only to collect the whole plant in the field. It was then transported as shocks to the farmstead to be processed. In many cases, the processing involved shredding the material into whole plant ensilage with machines which were the forerunners of our present day ensilage cutters. In 1890, J. F. Hurd patented a husker-shredder which was considered the first successful mechanical total corn harvester (67). The husker-shredder was a gasoline or steam powered stationary machine which was capable of dividing the corn plant into ear corn and stover ensilage. Bundles produced with the binder or shocker were placed butt first on the feeding apron where they were guided into a set of horizontal snapping rolls. The snapped ear was discharged down onto a husking bed and the stalks were fed into a shredder head where they were chopped and pneumatically conveyed to a stack. Figure 6 illustrates the major components of the husker-shredder.

Rosenthal

The first field mobile total corn harvesting machine was manufactured in 1951 by Rosenthal (~~40~~). The Rosenthal machine, known as a "cornbine", was a one-row husker-shredder which harvested the mature corn plant by snapping the ear and shredding the stalks all in one operation. The ears were collected in a wagon trailed behind the machine, the loose kernels from the snapping process were collected in a bag, and the stalks were shredded and blown into another wagon pulled beside the unit. The cornbine provided the option of collecting ear corn plus SILAGE ~~stover ensilage~~, or collecting only ear corn while the stalks were shredded and scattered on the ground for easy plowing and corn borer control. Rosenthal reported a field capacity of eight to ten acres per day when an auxiliary engine was used to supplement the tractor power. Figure 7 shows the Rosenthal cornbine in operation. (See Fig. 1).

J. I Case

J. I. Case (~~8~~) entered a licensing agreement with Rosenthal, designed a new machine, and successfully marketed a one-row pulled type total harvester. Success was short lived because the field capacity was low, large enough power

X

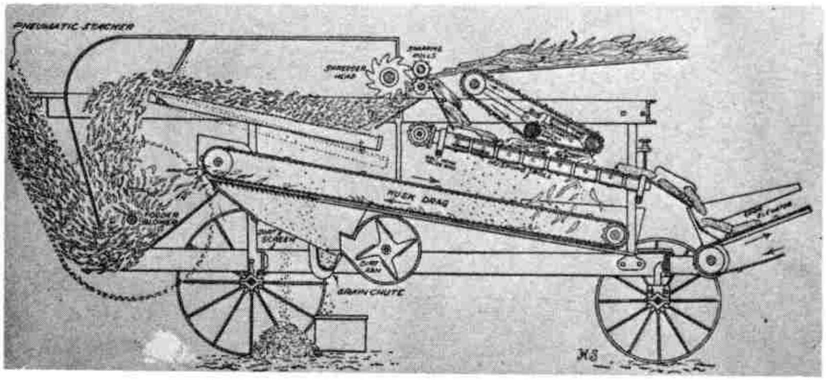


Figure 6. Schematic of a stationary husker-shredder, 1890

Figure 7. Rosenthal "cornbine" in field operation, 1951

units were not readily available, the wet corn presented a storage problem, the system required more labor than the conventional grain harvesting systems, and at that time beef cows were not a competitive enterprise in the Midwest. ~~Figures 8 and 9 show the Case total harvester.~~ (see Fig. 2 and 3).

Ferlemann

In 1966, Ferlemann ~~(13)~~ built a total corn harvester by mounting a modified forage chopper on a self-propelled combine. A two-row head was attached to the chopper and stripper plates were mounted above and parallel to the belted gathering chains in order to snap the ear from the stalk as the feed rolls on the chopper pulled the stalk between them. The ear was conveyed into the combine cylinder for threshing and the cobs and husks were discharged on the ground. The stalks were chopped and blown into a wagon which was towed beside the combine with a tractor. ~~Figure 10 shows the completed Ferlemann machine.~~ (See Fig 4)

The Ferlemann machine did not perform well in field tests because the feed rolls of the chopper were not positive enough to provide the force necessary to pull the stalk through the stripper plates for ear removal.

Beefmaker I

Schroeder ~~(41)~~, in 1967, modified the Ferlemann machine and produced a one-row total corn harvester popularily known as the "Beefmaker I". The basic Ferlemann machine was used, but a new row crop head was designed to improve the snapping performance. Hydraulically driven stalk rolls were mounted above the gathering belts at an angle of 23° with the row-crop head, and stripper bars were installed directly over the stalk rolls. A collection hopper was attached to the rear of the combine to salvage the cobs and trash from the shelling operation,

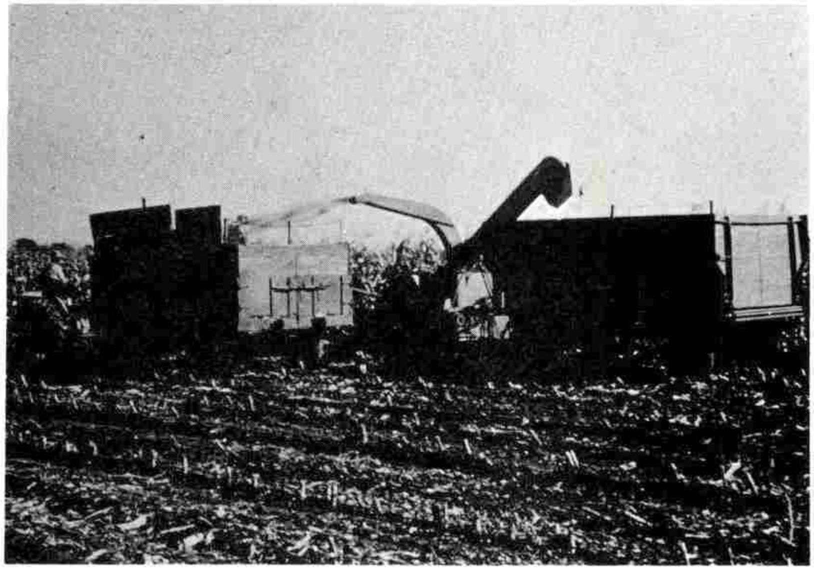
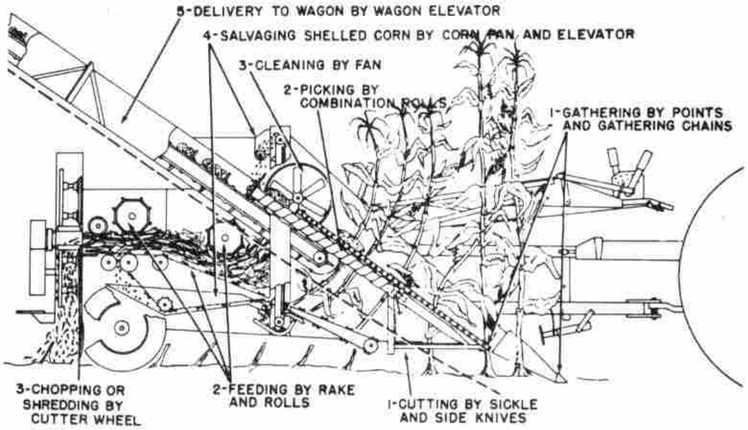


Figure 8. J. I. Case total corn harvester in field operation

CORN PICKING SECTION



STALK CHOPPING SECTION

Figure 9. Schematic of the Case total harvester

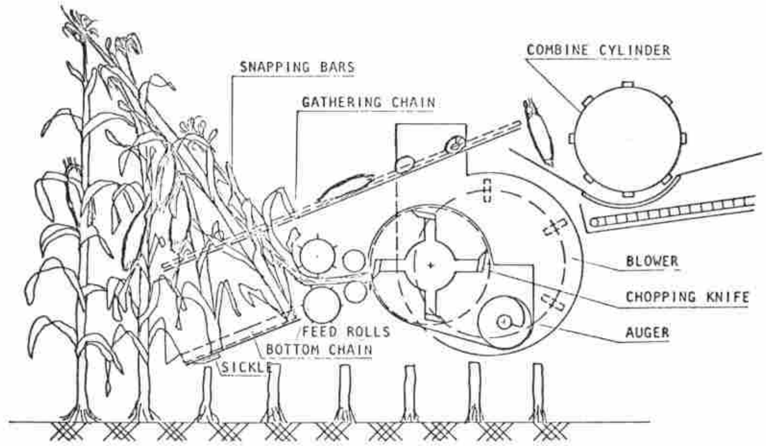


Figure 10. Schematic of the Ferlemann total corn harvester, 1966

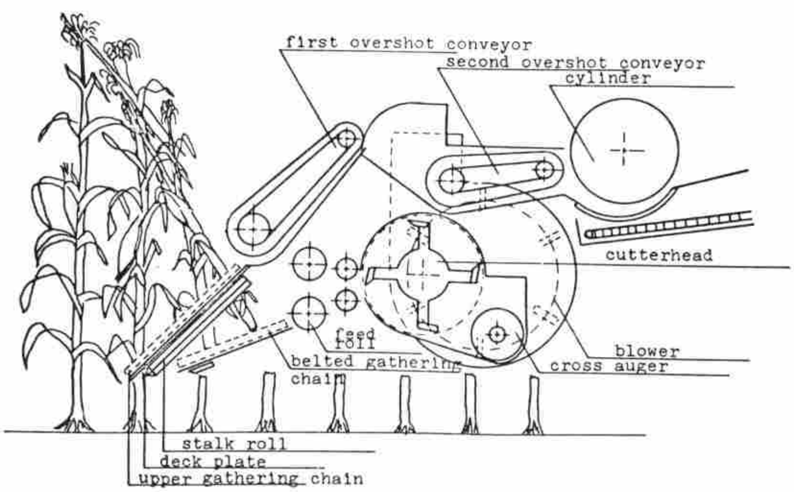


Figure 11. Schematic of Schroeder's Beefmaker I, 1967

and a conveyor returned this refuse material to the chopper to be included with the stalks. Field capacity of the Beefmaker I was limited by the combine engine and the one-row head, but the machine produced an acceptable product. Figures ~~11 and 12 show the main features of the Beefmaker I.~~ (See Fig. 5 and 6).

In recent years, several machines have been designed to harvest all or part of the corn plant. One such machine, called the Foster Blower and Harvest Master, was developed by Foster Manufacturing Company of Madras, Oregon (10, 66). A blower was designed to attach to the rear of a combine to collect the husks, cobs, and fines from the combine sieve, and that material was blown into a two-wheel trailer towed behind. When the Foster Harvest Master was full, it automatically dumped the material in a stack without interrupting the harvest operation. These stacks were either fed in the field or were transported to a storage area for winter feed. Large capacity combines could be used with this system, and a high energy feed product was obtained (10). Figure 13 shows a Foster blower mounted on a combine.

Hunt, at the University of Illinois, designed a machine which used a cut-off head and a rear mounted chopper on a self-propelled combine. The entire stalk was cut and fed through the combine cylinder to thresh the grain. The chopper shredded the material from the combine walkers and discharged it into a trailing wagon. The separating efficiency of the combine was reduced, but an acceptable product was produced (66).

Figure 12. Side view of the Beefmaker I

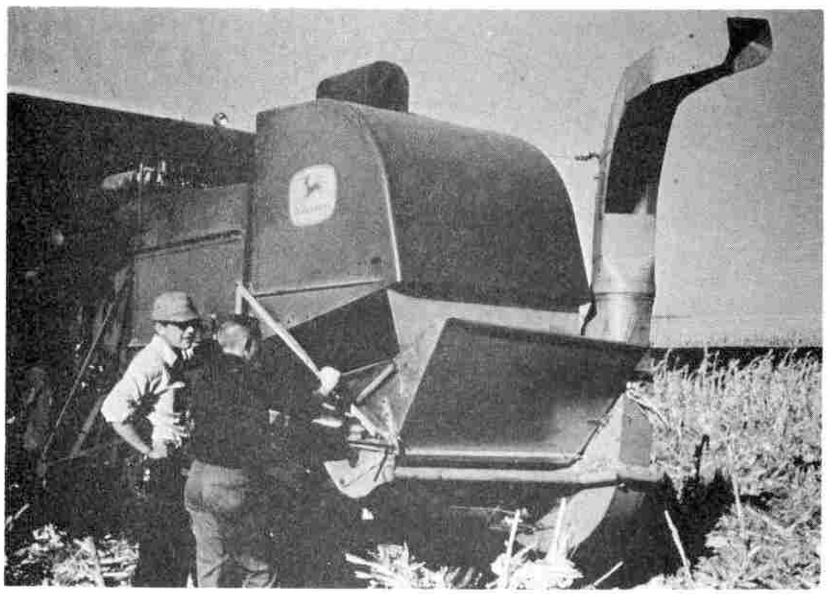


Figure 13. Foster blower mounted on a combine

A total harvesting system which the farming public empirically developed involved two separate operations but utilized machines which were commercially available. The grain was harvested with either a picker or a combine and the stalks were collected later in a separate operation with a flail chopper. That system was popular in the Corn Belt because it spread the use of labor over a long time and allowed the farmer to first collect the most valuable part of the crop, the grain. Also, the machinery was commercially available and the system allowed the manager to collect only as much stalk ensilage as he needed. However, the quality of the stalk product was considerably reduced because the cob, husks, and fines were lost in the field. The stalk rolls tended to crush the stalks and this permitted rapid drying which resulted in a dryer ensilage product with reduced palatability (10). Also, the flail chopper produced a very coarse product which had to be processed with a recutter before feeding (61).

Agricultural engineers in Russia developed some total corn harvesters which were widely used in that country. As Momotenko (35) explains, "Unlike the maize combine harvesters of the picker type manufactured abroad, which are designed only for snapping the ears from the stalks and sometimes also for husking them, the operations carried out by the maize harvesters used in the USSR also include the cutting and chopping of stalks and the loading of the chopped mass into vehicles for subsequent ensilage."

Russian machines

The KKKH-3 Khersonets harvester illustrated in Figure ~~14~~ 7 and the ZhKN-2.6 continuous cutting maize harvester illustrated in Figure ~~15~~ 8 are examples of

Figure 14. KKKh-3 three-row pulled type Russian total corn harvester

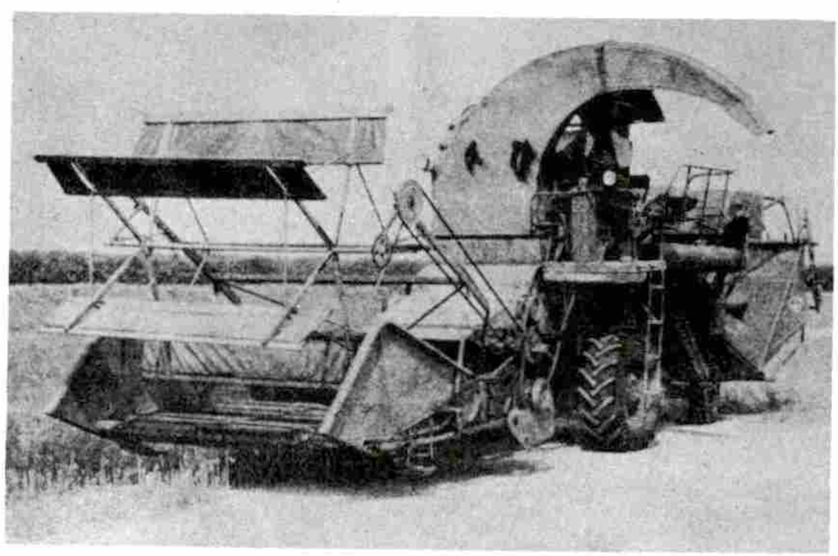


Figure 15. ZhKH-2.5 Russian total corn harvester with grain platform and horizontal snapping rolls

Russian total harvesters. The KKKH-3 was a three row pulled type pto-driven harvester. Each row unit included a set of spring tensional roller chains which gripped the base of the stalk and guided it into the high speed snapping rolls, (1,090 rpm). Three choppers mounted on a single shaft, one for each row, were positioned behind the snapping rolls and discharged the shredded material into a chain conveyor. The alleged field capacity was 1.7 to 2.0 acres per hour.

A sickle bar and grain platform mounted on a combine comprised the major components of the ZhKN-2.6 total harvester. A five bat reel placed the sheared stalks on a feeder apron which moved them to the spring loaded horizontal snapping rolls and chopper. Grain was collected in a tank and ensilage was blown into a truck. By raising the snapping device above the flow of the cut stalks, whole plant ensilage was produced. The feeder paddle which compressed the crop ahead of the snapping rolls was rubberized to minimize grain damage. Threshing was accomplished with a cylinder and the refuse from the combine was shredded with a second chopper mounted in place of the straw chopper. Momotenko (35) indicated that the labor requirement was reduced with the one operation machines, but the wet grain posed some drying problems.

Agriculturists in Germany and Hungary also have expressed an interest in total harvesting methods. Reporting on the philosophy at the Munich Agricultural Institute, Momotenko (35) said, "It is the thought at the Institute that the most promising methods of harvesting for the conditions in the Federal Republic of Germany are to pick the ears and thresh them simultaneously in a thresher-collector, or to harvest the whole plant and thresh the ears with grain combine harvesters."

Beef Trends

Beef cows traditionally were concentrated in the western states where an abundance of range land made cows a very competitive enterprise. Since feed grains were scarce in that area, the calves were shipped to the Corn Belt for fattening.

Importing calves from the West caused some problems for the corn belt farmers. Fluctuations in supply and demand of feeder calves resulted in uncertainty for the cattle feeders so that farmers were inclined to move in and out of the cattle business. Those who intended to feed cattle every year usually purchased calves directly from individual ranchers. By 1966, 60 percent of the feeder cattle purchases in Iowa were direct (24).

Shrinkage and shipping fever were very common and costly problems encountered when transporting calves to the Midwest. Herrick and Bristol (16) reported that the losses from shrink, poor feed utilization, improper drug use, and loss of gain were frequently hidden, but amounted to at least \$10 to \$20 per animal. In their study of 5,564 animals in transit less than 24 hours, 4.2 percent became ill and .6 percent died. When transported for more than 24 hours, 9.4 percent became ill and 1.6 percent died. They concluded that if the results of their investigation of 125,000 cattle shipped into Iowa were typical, then Iowa cattle feeders annually lose 31,616 head of cattle worth $4.75 million.

Consumer demands for beef are steadily increasing. Table 3 (41, 60) depicts the increased consumption of meat products in the U.S. and the percent of the total comprised of beef. From 1940 to 1968, total meat consumption per capita increased by 28 percent, but beef consumption doubled. From 1958 to 1968, consumption of beef increased by 36 percent and by 1968 it accounted for 60 percent of the meat diet. A change in tastes, increased disposable income, and the popularized "drive-in hamburger" all contributed to the increased beef consumption.

Burgeoning markets in the West, a demand for higher quality meat, and irrigated grain production motivated western ranchers to feed more of their own calves. Furthermore, western range experts report that the western ranges have about reached their capacity of beef-cow concentration (41) so the Midwest must find other sources of feeder calves. Table 4 indicates that 20.5 percent of the feeder calves imported into Iowa from 1962 to 1966 came from the western states (24).

One recent and productive source of calves has been the central states area. From 1962 to 1966, 49.3 percent of Iowa's imported calves came from the central states (24). However, Figure 2 indicates that these states are rapidly diminishing their surplus of feeder calves by expanding their feeding facilities.

Table 3. Per capita consumption of meat in the U.S. (pounds carcass weight)

Year	Beef	% of total	Veal	Pork	Mutton	Total
1940	54.9	38.5	7.4	73.5	6.6	142.4
1945	59.4	40.9	11.9	66.6	7.3	145.2
1950	63.4	43.8	8.0	69.2	4.0	144.6
1955	82.0	50.4	9.4	66.8	4.6	162.8
1956	85.4	51.2	9.5	67.3	4.5	166.7
1957	84.6	53.3	8.8	61.1	4.2	158.7
1958	80.5	53.1	6.7	60.2	4.2	151.6
1959	81.4	51.0	5.7	67.6	4.8	159.5
1960	85.0	52.9	6.1	64.9	4.8	160.8
1961	87.7	54.7	5.6	62.0	5.1	160.4
1962	88.8	54.5	5.5	63.5	5.2	163.0
1963	94.3	55.7	4.9	65.3	4.8	169.3
1964	99.8	57.2	5.2	65.3	4.2	174.5
1965	99.3	59.6	5.2	58.5	3.7	166.7
1966	104.0	61.0	4.5	58.0	4.0	170.5
1967	105.9	59.7	3.8	63.9	3.9	177.5
1968	109.6	60.0	3.5	65.8	3.8	182.7

Table 4. Origin of feeder cattle and calves shipped into Iowa

State	Percent of total, 1962-1966 average
Colorado	3.7
Wyoming	3.9
Montana	12.9
Western	20.5
Nebraska	14.5
South Dakota	11.6
Kansas	7.5
Texas	7.6
Oklahoma	4.1
North Dakota	4.0
Central	49.3
Canada	7.2
Missouri	9.5
Other	13.5
	30.2

Another source of calves is native cow herds. By 1969, Iowa accounted for 3.9 percent of the beef cows in the U.S. and these were concentrated in the southern and eastern counties of the state. From 1954 to 1967, beef cow numbers increased in the state by 34 percent; and by 1967 there were 1.11 million beef cows in Iowa (23). On January 1, 1969, 1.41 million head were inventoried in Iowa (57).

In spite of the increased number of beef cows in the state, the supply of indigenous calves has not kept pace with the demand. The deficit of feeder calves in Iowa increased by five times from 488 to 2,581 thousand head between 1954 and 1967.

In the Midwest, the beef cow herd has not historically represented a major farm enterprise. Other activities appeared to be more competitive so beef cows became a part of the farm plan only if permanent pasture was available such that the cow herd didn't detract from other enterprises[1]. In most cases, the cows grazed the cornstalk fields during the winter months.

Vetter and Buchele (61) reported that cows could utilize the stalks in the field and adequately maintain themselves during the winter. However, Figure 16 shows a stalk field being grazed in Iowa where the snow cover has seriously reduced the availability of the feed. The large capital investment expended for a cow herd demanded that it be a long-range enterprise which ultimately required

---

[1] Beneke, R. R., Ames, Iowa, Iowa State University of Science and Technology. Economics of a beef cow herd. Private communication. 1969.

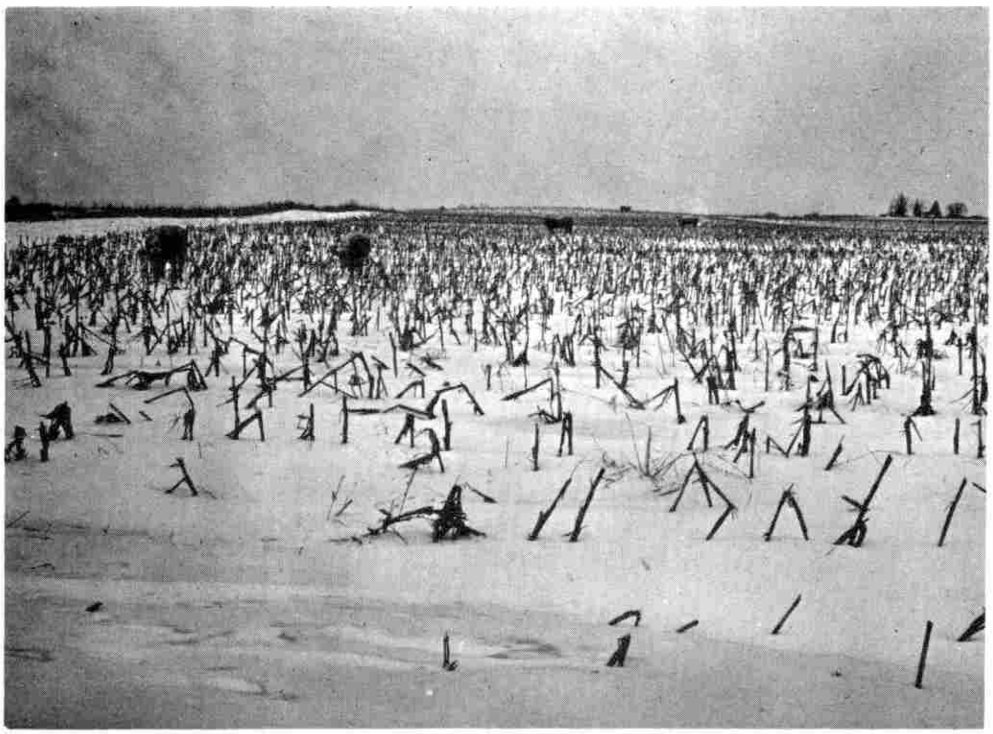


Figure 16. Beef cows grazing cornstalks in Iowa where the snow cover has seriously reduced the availability of the feed, January, 1969

a reliable and consistent source of winter feed. Cornstalk grazing provided a suitable feed product but not a reliable source on which to depend[1] (6).

Researchers have predicted that one to two acres of cornstalks properly supplemented would maintain a cow and calf over the winter months (6, 10, 61). Gay and Zmolek (14) summarized the value of cornstalks in terms of cow-days carrying capacity as recounted in Table 5. Their results assumed 22 pounds per day consumption when grazing, 45 pounds consumption per day of ensiled stalks, and harvesting losses of 20 percent. The increased consumption of ensiled stalks resulted from improved palatability and increased moisture content. Other researchers estimated carrying capacity as high as 400 cow-days per acre of harvested stalks.

Table 5. Estimated cow-day carrying capacity of cornstalks at three different yields and three harvesting methods

Grain yield	Cow carrying days		
bushels per acre	Stalks ensiled	Stalks baled	Stalks grazed
80	133	112	60
100	160	140	75
120	191	168	90

[1]Greiner, Howard, Wellman, Iowa. Beef cow production in Iowa. Private communication. 1969.

Machinery is needed to harvest and process the entire plant such that the grain can be used for fattening or selling while the refuse material is used to maintain a beef cow herd (6, 7, 34, 61, 64). Thus the operator utilizes refuse to maintain his beef cows which provide calves that consume the grain[1].

---

[1]Greiner, Howard, Wellman, Iowa. Beef cow production in Iowa. Private communication. 1969.

SYSTEM ANALYSIS

Model

Research and records have produced data for many individual segments within a total corn harvesting system. However, to date very few attempts have been made to numerically simulate the overall system. Many of the coefficients required to thoroughly analyze a refuse retrieval system are not yet available, but enough values have been measured to permit at least a partial analysis.

Linear programming techniques utilizing Iowa State University's IBM MPS/360 system were used to analyze a hypothetical midwestern farm. The system permitted various cropping and livestock production activities to compete with each other for the use of the limited resources. The various outcomes were compared only by net farm income and without regard to risk, operator personal preferences, social or psychological implications, or other intangible factors. In this study, net farm income included the returns to the operator for his labor and management; and it should be regarded as the expected average return to the farm over the planning horizon, rather than income for any given year.

The validity of the linear program depends on the accuracy of the coefficients assigned to the various restraints and production activities. An attempt was made to select meaningful and objective coefficients based on farm records and current published data, but the inconsistencies which exist in the available data invite a certain amount of caution and judgment. These limitations are identified in the discussion of activities.

Data required to formulate coefficients were obtained from the Midwest Farm Planning Manual (27), the Stoecker program (44), ASAE Yearbook (3), Gay and Zmolek (14), Hoglund (18), Hull, et al. (19), Johnson and Nodland (28), Morrison's Feeds and Feeding (36), and Stoneberg et al. (45).

The main objective of the linear program analysis was to look at corn refuse retrieval as a possible enterprise for midwestern farms, and to evaluate that system relative to current practices. The refuse product was assumed to have a value only as bedding and as a beef cow maintenance ration. Industrial and projected future uses of stalks were not considered in this study, but they could have a significant influence on the system in the future.

A model farm was arbitrarily defined to represent a typical midwestern farm. The organization consisted of a father and son partnership where the older partner provided the capital and the younger partner provided the major share of the labor. Geographically, the farm was located in northern Iowa in the Clarion Webster soil district. Total land available was 640 acres of which 540 were cropable and 100 acres were improved bluegrass pasture. Four hundred ninety acres were considered suitable for continuous corn or a corn and soybean rotation, and were homogeneous to the extent that equal treatment would result in equal yields from any area. Adequate buildings were available for crop storage and livestock production enterprises, and it was assumed that extensive construction or remodeling expenses would not be incurred to accommodate any of the activities offered.

The cropping activities included corn, soybeans, sorghum, hay and pasture. Livestock activities included hogs, beef cows, steer feeding, and heifer feeding.

Figure 17 outlines the basic model structure. The land, labor, and capital restraints were entered into the program numerically, but management was a subjective restraint which limited the size of the enterprises within the scope of the management ability of the operators. The labor resource was restricted for the amount of family labor available as well as the amount of hired labor obtainable. Hired labor was considered more plentiful and cheaper during the summer months when students could be hired.

Field tractor units were included in the program to account for field work restrictions due to weather conditions, even though adequate machinery and labor might be available. The coefficients were based on the number of suitable field days per month, number of tractors available, and the number of operators available. Field tractor units were computed for operating one tractor 14 hours per day and another tractor ten hours per day for the available field days as listed in Table 6 (27).

As indicated in Figure 17, different harvesting options were provided for the cropping activities. The crops could be fed to the livestock or sold directly to contribute to net farm income.

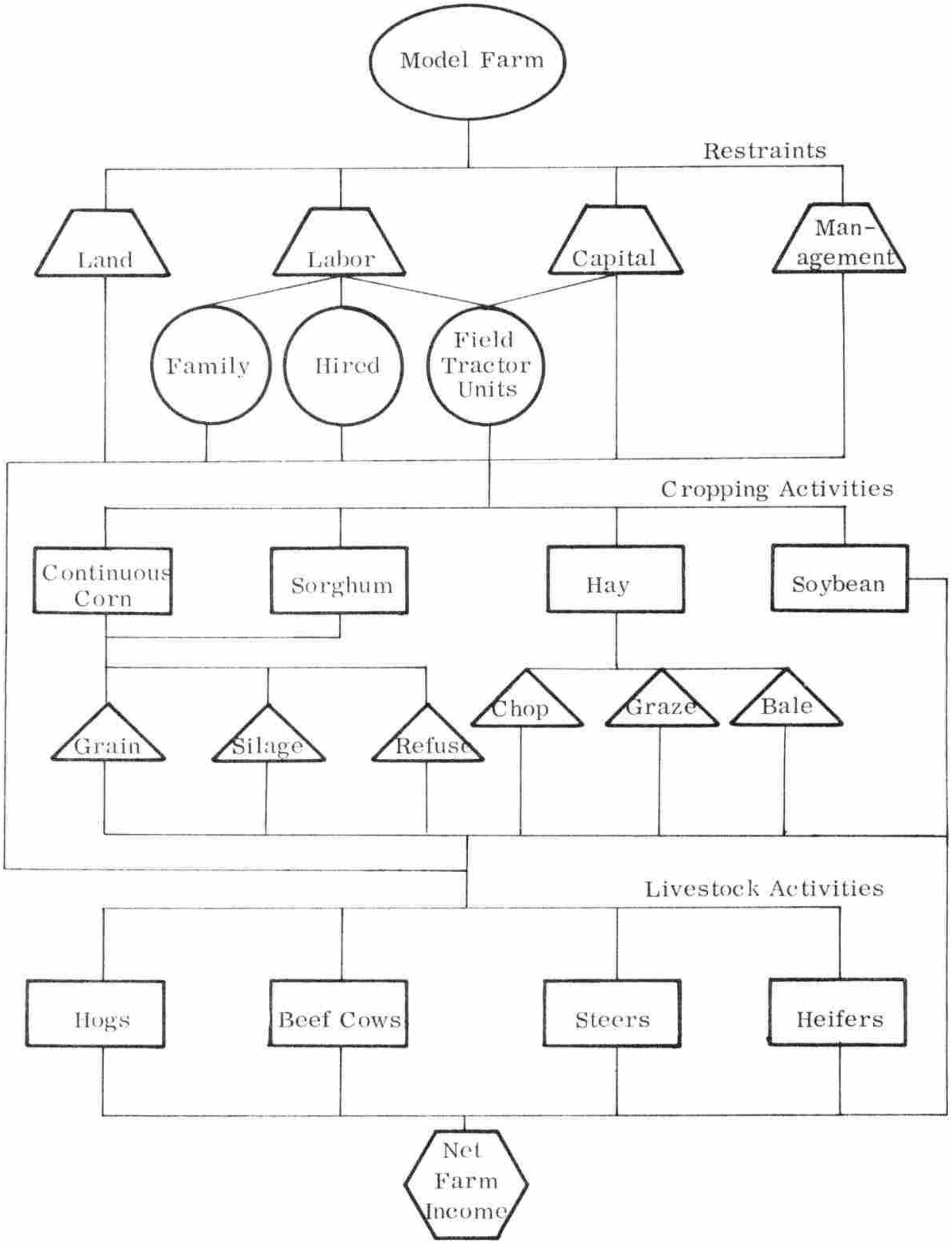


Figure 17. Schematic diagram of linear program model

Systems

Four different systems were programmed and compared. System I included the usual cropping and livestock activities, but beef cows were fixed at a level of 100 cow units. The amount of hired labor was limited as indicated in Table 7.

System II also fixed the beef cow activity at 100 cows, but the labor hiring activity was unrestrained.

System III allowed the beef cow enterprise to compete with the other production activities, but the hired labor was restricted to the same level as indicated for system I.

System IV allowed the beef cow enterprise to compete with the other production activities and provided an unlimited amount of hired labor.

The four systems are summarized as follows:

System I: 100 beef cows and limited hired labor

System II: 100 beef cows and unlimited hired labor

System III: unlimited beef cows and limited hired labor

System IV: unlimited beef cows and unlimited hired labor.

Restraints

The resource and production activity restraints are listed in Table 8. Most of these levels were determined by the model definition.

The operator labor available during the slack seasons was determined by assuming a work week of 40 hours for the senior partner and 48 hours for the junior partner. The Spring and Fall were considered to be peak labor demand seasons and it was assumed that during these periods the senior partner would be willing to work ten hours per day and the younger partner would work 14 hours per day.

The cost of the hired labor was \$2.00 per hour during the Summer, and \$2.50 per hour during the Spring and Fall.

Table 6. Favorable field working days available per month (90 percent probability)

Month	Suitable field days[a]
April	13
May	17
June	17
July	19
August	19
September	19
October	19
November	13

[a]Data taken from Midwest Farm Planning Manual (27)

Table 7. Hours of operator labor available and maximum hours of semi-skilled labor hired for each month

Month	Operator labor[a], hours Systems I, II, III, and IV	Hired labor, hours Systems I and III	Hired labor, hours Systems II and IV
January	352	0	0
February	352	0	0
March	352	0	0
April	352	40	*[b]
May 1-15	313	28	*
May 16-31	313	28	*
June 1-15	313	192	*
June 16-30	313	192	*
July	352	0	0
August	352	0	0
September	352	0	0
October 1-15	313	48	*
October 16-31	313	48	*
November 1-15	313	48	*
November 16-30	176	0	0
December	352	0	0

[a]Operator labor was computed for a father and son partnership

[b]Labor hiring activity unrestricted

Table 8. Resource and activity restraints

Resource or activity	Type of restraint	Restraint unit	Restraint level
Land	Maximum	Acre	640
Continuous corn	Maximum	Acre	490
Sorghum	Maximum	Acre	50
Pasture	Equality	Acre	100
Hog Production	Maximum	Litters/year	50
Beef cows	Equality	Cow unit	100
Capital borrowing	Maximum	Dollar	50,000
Field tractor units			
April	Maximum	Hours	273
May 1-15	Maximum	Hours	204
May 16-31	Maximum	Hours	204
June 1-15	Maximum	Hours	204
June 16-30	Maximum	Hours	204
October 1-15	Maximum	Hours	238
October 16-31	Maximum	Hours	238
November 1-15	Maximum	Hours	156

Activities

Coefficients derived for the crop and livestock production activities are summarized in Tables 9 and 10. The cropping machinery included a 100 hp tractor and six-row equipment. Corn yielded 110 bushels per acre of $1.05 grain, 19 ton of silage, or 104.5 bushels of grain and 3.5 ton of refuse per acre. Five percent of the total grain yield was considered to be included with the refuse due to the separating inefficiency of the total harvesting machinery.

Net cost per acre for harvesting the corn for grain was $13.41. This estimate included $6.50 for harvesting costs, $2.40 for storage, $3.90 for drying, and $.61 for hauling. The total harvesting operation included $8.00 machine costs, $5.48 tractor costs, $2.50 for hauling, $3.72 for drying, $3.16 for storage, $.61 for grain transporting, and a total net cost of $23.45 per acre. Subtracting the proportion of the cost due to the grain resulted in a refuse harvesting cost of approximately $3.00 per ton.

The total corn harvester had capacity for two 30-inch rows at 2.5 mph with 70 percent field efficiency and a field capacity of 1.06 acres per hour. Four men were required to operate the system and a total of six hours were expended to harvest, store, and feed each acre. Harvesting and storing required 4.8 hours per acre and feeding required 0.35 hours per ton.

Prices assumed for computation of the livestock activity coefficients were the following:

Sell steer calves	$30.00/cwt

Sell heifer calves	\$24.00/cwt
Buy steer calves	\$31.00/cwt
Sell cull cow	\$14.00/cwt
Sell fat steers	\$24.00/cwt
Sell fat heifers	\$23.82/cwt
Sell fat hogs	\$19.00/cwt
Sell sows	\$16.00/cwt

A beef cow unit consisted of 1.0 cow, .45 steer calf, .45 heifer calf, .16 replacement heifer, and .04 bull.

Corn selling, hay harvesting, fixed cost paying, hay selling, and custom harvesting activities were also included in the program.

Custom hire operations were provided to allow the owner operator to make more use of his machinery if labor and field time permitted. Corn ensilage was harvested for \$6.50 per acre with machinery operating costs of \$3.49 which resulted in a \$3.01 return for labor plus risks of machinery ownership. Custom combining was contracted for \$7.00 per acre with a \$2.45 return for labor and machinery investment. Nine dollars per acre were charged for total harvesting of which \$4.31 was operating cost and \$4.69 was the return for labor and machine ownership. Only variable costs were charged to the custom operations because all fixed costs were absorbed by the operators own acreage. It was assumed that the machinery was available so fixed costs were paid whether or not the machine was custom operated.

Table 9. Crop and livestock production activity coefficients used in the linear program

Activity	Activity unit	Net price per unit[a]
Continuous corn raising	Acre	-$47.16
Corn harvest for grain	Acre	-$13.41
Corn harvest for silage	Acre	-$21.65
Corn harvest for refuse	Acre	-$23.45
Soybean raise and sell	Acre	$50.20
Sorghum raise and harvest	Acre	-$66.46
Pasture maintenance	Acre	-$2.74
Hog production and selling	2 Litters	$464.39
Beef cow calf production	Cow unit	-$44.52
Sell steer calves	Head	$157.50
Sell heifer calves	Head	$114.00
Buy steer calves	Head	-$162.90
Long fed steers	Head	$225.38
Long fed heifers	Head	$204.48
Hay harvesting	Acre	-$7.51
Hay harvesting - 2 cuttings	Acre	-$14.14
Hay selling	Ton	$18.00
Corn selling	Bushel	$1.05
Labor hiring - slack season	Hour	$2.00
Labor hiring - peak season	Hour	$2.50

[a]Net price includes all costs and returns except those specifically accounted for within the program

Table 10. Labor requirement per month per unit for crop and livestock activities

Month	Hours of labor per unit							
	Corn raising	Corn harvesting for grain	Corn harvesting for refuse	Soybean raising and selling	Hog production	Beef cow	Steer feeding	Heifer feeding
January	0.08			0.06	4.28	1.06	1.06	0.98
February	0.06			0.06	2.22	0.88	0.95	0.78
March	0.14			0.15	3.02	1.21	1.08	0.89
April	0.49			0.47	2.58	0.94	0.99	0.86
May 1-15	0.32			0.23	1.16	0.25	0.48	0.45
May 16-31	0.32			0.23	1.16	0.25	0.48	0.45
June 1-15	0.26			0.32	2.29	0.20	0.45	0.42
June 16-30	0.26			0.32	2.29	0.20	0.45	0.43
July	0.27	0.19		0.58	4.04	0.30	0.88	0.44
August	0.25			0.32	2.36	0.30	0.97	0.17
September				0.55	2.82	0.30	0.59	0.19
October 1-15		0.50	3.0	0.19	1.09	0.15	0.29	0.29
October 16-31		0.51	3.0	0.10	1.09	0.15	0.29	0.29
November 1-15		0.51		0.05	1.24	0.22	0.45	0.44
November 16-30	0.10			0.05	1.24	0.22	0.46	0.45
December		0.08		0.10	2.88	0.86	1.06	1.03
Total	2.55	1.79	6.0	3.78	35.76	7.49	10.93	8.56

Results

The results of the linear program analysis are summarized in Tables 11-15. Table 11 includes a list of the cropping and livestock activities in each system, and Table 12 lists the labor required for each system. Tables 13 and 14 depict the shadow prices for the limiting resources and activities not in the basis, and Table 15 reviews the field tractor units required to optimize each system.

Net farm income was greater for Systems II and IV where labor hiring was unrestrained. Both systems hired a large amount of labor to optimize income, but the 1159.7 hours hired in October for System IV was unrealistic. In view of the fact that net farm income was the return to two families, Systems II, III, and IV were acceptable, but System I was not. Income for System I was low because beef cows were forced in at 100 units which required a total harvesting operation. That in turn demanded so much labor that the corn could not all be harvested, and as a result 51 acres of $600 land remained uncropped. October labor had a marginal value product of $256.79 per hour as indicated in Table 13.

Corn was a profitable enterprise for Systems II and IV where labor was available, and the corn enterprise contributed much to the net income. Most of the corn was harvested for grain, dried, and sold commercially for $1.05 per bushel. However, when labor was available, total harvesting and refuse fed beef cows were competitive enterprises. For both systems which had unlimited labor supplies, the extent of total harvesting was finally limited by the field tractor

Table 11. Net farm income and the level of production for the cropping and livestock activities in the optimum farm plan for four systems

Activity	Unit	Optimum level for each system			
		I	II	III	IV
Net farm income	Dollar	2,376.88	12,566.77	9,958.64	15,205.99
Land utilized	Acre	588.9	640.0	640.0	640.0
Continuous corn	Acre	91.4	490.0	297.4	490.0
Soybeans	Acre	377.4	30.0	231.6	5.6
Corn harvested for grain	Acre	0	386.6	243.7	273.0
Corn harvested for silage	Acre	0	11.9	3.5	14.1
Corn harvested for refuse	Acre	91.4	91.4	50.2	202.9
Sorghum	Acre	20.0	20.0	11.0	44.4
Hogs	Litter	0	50.0	50.0	50.0
Beef cows	Cow unit	100.0	100.0	54.9	221.9
Feed steers	Head	0	39.2	0	0
Buy steers	Head	0	0	0	0
Sell steer calves	Head	45.0	5.8	24.7	99.8
Sell heifers	Head	45.0	0	0	0
Feed heifers	Head	0	45.0	24.7	99.8
Hay harvest	Acre	60.0	48.8	66.8	0
Custom silo filling	Acre	0	179.4	0	156.7
Custom combine	Acre	0	79.5	0	44.4
Sell corn grain	Bushel	9,554.3	44,061.0	25,988.3	43,073.7
Sell hay	Ton	180.0	146.3	200.3	0

Table 12. Hours of labor hired and total hours of labor utilized by the optimum farm plan in each system for selected months

Month	Hours of labor for each system							
	I		II		III		IV	
	Hired	Total	Hired	Total	Hired	Total	Hired	Total
March	0	190.4	0	352.0	0	240.4	150.3	502.3
April	0	316.2	138.2	490.2	40.0	392.0	249.7	601.7
May 1-15	0	141.1	0	256.8	0	202.3	0	287.5
May 16-31	0	161.1	0	276.8	0	222.3	0	307.5
June 1-15	0	241.0	3.6	316.6	0	312.8	0	292.8
June 16-30	0	227.0	0	303.1	0	296.4	0	287.1
September	0	288.6	14.3	366.3	0	297.5	0	352.0
October 1-15	48.0	361.0	346.6	659.6	48.0	361.0	621.5	934.5
October 16-31	14.0	327.0	252.0	565.0	27.8	340.8	538.2	851.2
November 1-15	0	40.9	0	313.0	0	189.8	0	276.6

units available in October, as indicated in Table 15. Corn harvesting for silage was not very attractive in any of the systems because beef feeding activities were not competitive due to the high price of calves.

Soybeans were competitive in Systems I and III where labor was limited, but they were replaced by corn production when labor permitted. Table 10 indicates that the total labor required for soybeans was slightly less than for raising and harvesting corn, but the big advantage of soybeans to the labor deficit systems was the labor distribution by months.

Hogs entered Systems II, III, and IV at the maximum level and were very competitive as indicated by the shadow prices listed in Table 13. The hog enterprise was surpressed in System I by the scarcity of labor. In all cases, the hog enterprise outcompeted the beef cow enterprise, but the program did not account for the higher equipment and housing costs usually incurred with hog production. The hog activity may have been favored by the 7.5 pig per litter weaning average and the $19.00 per cwt selling price.

The beef cow enterprise was forced into Systems I and II at 100 cow units but it was a competing enterprise in Systems III and IV. The large number of cows in System IV was due to an economical ration utilizing refuse ensilage, plus enough labor available to harvest the refuse. Even in System III where labor was limited, the beef cow activity was competitive and entered the program at a level of 55 cow units. It was restrained at that level by the limited amount of labor available in October to harvest the refuse.

Table 13. Marginal value product of last unit of resource used by the optimum plan for each system

Resource	Units	Marginal value product[a], dollars			
		System I	System II	System III	System IV
Land	$/acre	--[b]	44.50	42.81	45.84
Hogs	$/2 litters	--	94.24	89.82	79.07
Beef cows	$/cow unit	-665.62	28.88	--	--
Additional corn	$/acre	--	3.73	--	3.11
Pasture	$/acre	33.38	20.90	15.43	31.40
April labor	$/hour	--	2.00	6.19	2.00
October labor	$/hour	256.79	2.50	12.78	2.50

[a]Marginal value product is the amount that the net farm income would increase if one more unit of the resource were made available

[b]Marginal value product is zero because this resource is not limiting

Cattle feeding activities were not able to compete with the other enterprises. The steer calves were sold at 525 pounds for $30.00/cwt and the heifers were either sold at $24.00/cwt at 475 pounds or were fed to 945 pounds and sold for $23.82/cwt. The heifers had slower gains and sold for less than the slaughter steers, but were more competitive as feeders because they were cheaper as calves and were not fed as long as the steers.

Table 14. Opportunity cost for production activities not used

Activity	Units	Opportunity cost[a], dollars			
		System I	System II	System III	System IV
Hog production	$/2 litters	68.32	--[b]	--	--
Purchase steers	Head	5.40	5.40	5.40	5.40
Feed steers	Head	46.46	--	1.56	1.03
Feed heifers	Head	14.83	--	--	--
Sell heifers	Head	--	34.52	32.47	31.94
Hay harvest	Acre	14.97	7.47	8.97	32.37
Custom silo filling	Acre	125.38	--	3.37	--
Custom combining	Acre	75.34	--	2.13	--
Custom total harvesting	Acre	253.35	0.58	9.34	2.23

[a]Opportunity cost is the amount by which the net farm income would decrease if one unit of the activity were forced into the program

[b]The opportunity cost is zero because this activity is included in the optimum farm plan. Forcing in one unit of this activity would force out a unit of the same activity for a net change of zero

Custom silo filling and combining were profitable only when an adequate amount of labor was available. When labor was not available, the custom harvesting activities became very costly as indicated by the opportunity costs for

System I in Table 14. Only operating costs were charged to the custom operations because fixed costs were absorbed by the home farm.

Labor during the fall harvesting season was more restricted than during the planting season. That was a result of the high labor requirement for total corn harvesting. The development of high capacity total harvesting and refuse handling machinery would tend to relax the demand for labor, and would make the total harvesting activity more competitive.

Total corn harvesting machinery separating inefficiency caused 5.5 bushels of corn grain per acre to be included with the refuse. That five percent loss was based on data from experimental machines, but higher efficiencies could be expected from production harvesters. The grain was the primary source of income from the corn crop so the five percent loss charged to total harvesting suppressed the profitability of the activity.

The effect of wage rate on net farm income is illustrated in Table 16. The optimum mix of activities was not altered greatly by the reduction in labor costs. In most cases, the level of activities remained unchanged while silage harvesting, steer feeding, and custom harvesting activities entered the basis. The major part of the increased net income resulted from the new production activities rather than the direct savings from the reduced cost of labor. From Table 16, the total increase in net farm income for System IV was $2,142.78 when labor was reduced by $1, but only $770 was directly attributed to the savings from lower labor rates.

Table 15. Field tractor units required in the optimum plan for each system for selected months

Month	Field tractor units, hours			
	System I	System II	System III	System IV
April	222.2	254.2	254.6	242.7
May 1-15	116.1	163.7	148.4	158.1
May 16-31	136.1	183.7	168.4	178.1
June 1-15	164.6	157.0	171.4	149.2
June 16-30	144.6	137.0	151.4	129.2
October 1-15	111.9	238.0*	115.2	238.0*
October 16-31	78.0	144.4	94.0	157.7
November 1-15	28.0	151.7	90.1	117.2

*Limited the program

Discussion

The linear program provided an objective analysis of a total corn harvesting system. It indicated that if adequate labor were available, refuse retrieval for maintaining beef cows could be a profitable enterprise on a midwestern farm.

One of the limitations of the program was imposed by the selection of a typical farm. The techniques used in the analysis were valid, but the specific

Table 16. Net farm income with varying labor costs for three systems

Hired labor cost $/hour	Net farm income, dollars System II	System III	System IV
2.50[a] 2.00[b]	12,566.77	9,958.64	15,205.99
2.25 1.75	12,815.56	10,049.03	15,680.55
2.00 1.50	13,072.76	10,139.42	16,181.40
1.75 1.25	13,330.64	10,234.72	16,723.30
1.50 1.00	13,590.32	10,337.04	17,368.77

[a]Labor costs during peak seasons

[b]Labor costs during slack seasons

results applied only to the model farm as defined. Each individual farmer would have to supply his own coefficients to the program to determine if total corn harvesting would be profitable for his operation.

Net farm income was the only criteria for judging the systems because the analysis was objective. However, every operator imposes some subjective restraints which could alter the outcome considerably.

Government programs were not included because they are so variable. In most cases, including government programs would encourage the beef cow enterprises, due to some grazing opportunities on retired acres.

The program did not account for economies due to scale nor for diminishing returns. However, errors due to these factors would not be very great for the size of the farm model analyzed.

The development of synthetic meat substitutes and expanded industrial uses of cornstalks could each influence the total harvesting system of the future. This research effort was based on the assumption that demand for beef will continue to increase at the present rate, and beef cow maintenance will be the primary use of cornstalks.

The analysis showed that beef cows were a profitable enterprise if labor were available to harvest the refuse. That conclusion resulted in spite of the fact that five percent of the grain was assumed lost in total harvesting, and grain drying costs were charged to the total harvesting system. Many livestock operations would eliminate drying costs and utilize the wet grain.

The coefficients used for the total harvesting operation were based on the performance of experimental machines, while coefficients used for conventional harvesting methods were based on commercially available machines developed over a period of years. In fairness to the total harvesting system, a thoroughly developed total harvester should be used to formulate the coefficients for the program.

As more and better data are collected, new coefficients should be formulated and a linear program analysis repeated to obtain a more accurate perspective of total corn harvesting in the Midwest.

HARVESTING MACHINERY

The quest for greater returns per acre from midwestern cornland, and changes in price-cost relationships encouraged the development of total corn harvesting machinery in the 1960s. Prior to 1968 several systems had been designed but each had its disadvantages. The two-operation systems, which harvested the stalks with a flail harvester after the grain had been combined, had the major limitation of losing the cobs, husks, and grain chips; and as a result a lower quality feed product was obtained (7). Also, the stalks dried rapidly after the combine crushed them resulting in reduced palatability of the product. The combine systems which threshed the entire corn plant suffered from reduced separating capacity; and the combines with the mounted forage choppers lacked the horsepower necessary to harvest two rows simultaneously. The Foster blower concept was popular but it only salvaged the material from the combine sieves and walkers and the majority of the stalks remained in the field. That system also required supplemental water to insure proper ensiling because the husks and fines contribute a small part of the moisture in the refuse ensilage (41, 45). An additional operation of grinding or rechopping the material was performed to produce a suitable feed product (10). Most of the systems listed above were costly to own and operate, and some required an extensive modification of conventional equipment.

Design Parameters

In the summer of 1968, a new total corn harvester was designed. It was felt that the new machine should:

1. Process the entire corn plant.
2. Have adequate capacity to harvest two or more rows at two to three mph.
3. Be capable of operating efficiently under a variety of field conditions.
4. Collect whole plant ensilage, or ear corn and stover ensilage, or shelled corn and refuse ensilage with the same machine.
5. Include a collection system for two products.
6. Have high separating efficiency.
7. Be easy to operate and maintain.
8. Be simple and compact.
9. Be economical.
10. Sacrifice very little in grain recovery in order to retrieve the refuse.

Design and Construction

A forage chopper was selected as the basic machine to be used in the design of the experimental total harvester. Forage choppers were capable of handling a large volume of material and were designed to impart a considerable amount of energy to the corn stalk. Both of those factors were considered essential in a successful total harvester and limitations here probably were responsible for the majority of failures in existing methods. It was decided that grain harvesting components would be added to conventional forage harvesting machinery rather than add chopping components to conventional grain harvesters. However, grain was still considered the primary purpose for the corn crop and very few sacrifices could be afforded to retrieve the refuse.

A John Deere model 38 forage harvester was selected for the basic unit. Figures 18 and 19 show the production John Deere forage harvester. The two-row 30-inch row crop head was removed and a snapping unit was designed to mount between the row crop head and the chopper body. Attaching points on the snapping unit were designed to conform to the chopper attaching pins so that the original chopper remained unaltered. Figures 20, 21, and 22 illustrate the snapping unit frame.

Several different concepts for snapping the ear from the stalk were considered, including horizontal snapping rolls, vertical rolls, or rolls mounted on a 45^{0} angle with the ground. The horizontal design was chosen because it offered a simple drive system and did not alter the flow pattern of material from the row crop head to the feed rolls.

Several compromises were required in the design of the snapping rolls. A close spacing between the rolls would reduce the amount of butt shelling when the ears were snapped; however, a wider spacing would increase the capacity of the rolls. Capacity was a concern because a stand of 21,000 plants per acre requires a plant every ten inches for each row, so a two-row machine traveling at 2.5 mph must harvest 8.8 plants per second.

Figure 18. Conventional model 38 John Deere forage chopper

Figure 19. Forage chopper with two-row crop head

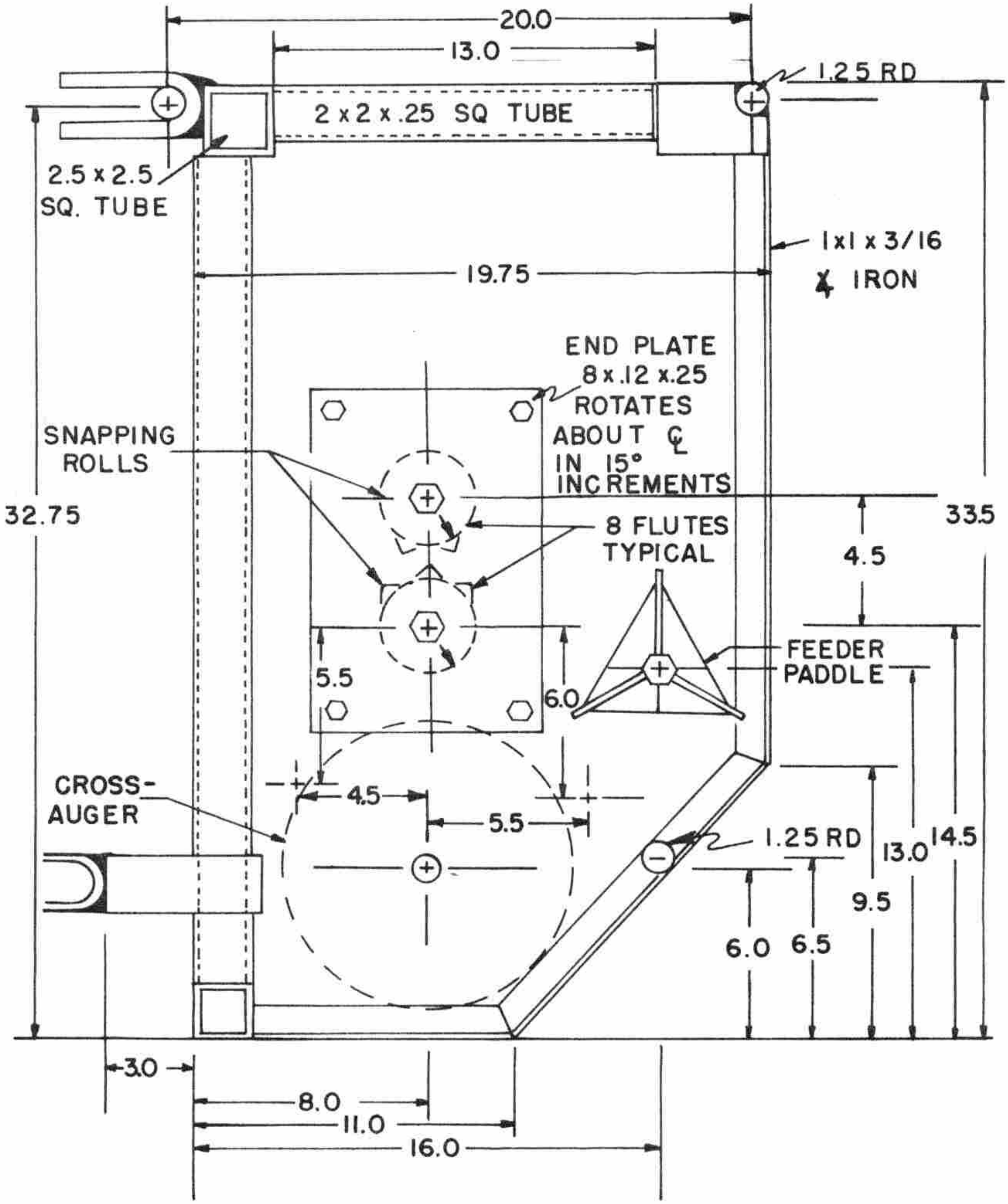


Figure 20. Diagram of snapping unit (side view), dimensions in inches

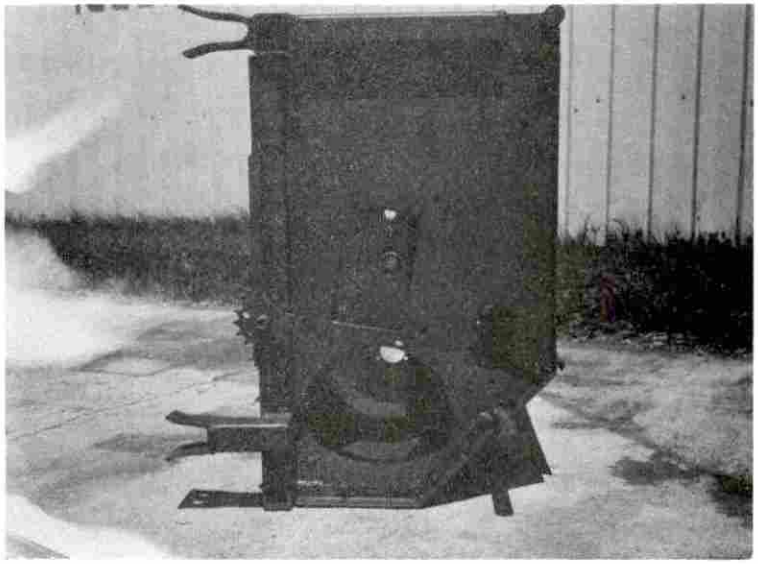


Figure 21. Experimental snapping unit frame (side view)

Figure 22. Experimental snapping unit frame (rear view)

Small snapping rolls were preferred to minimize the shelling losses, but large rolls provided more strength and reduced the precision required of the feeder paddle since the large rolls were capable of gathering the approaching stalks.

High speed rolls were desired for high capacity, but the perhipheral speed of the snapping rolls had to match the perhipheral speed of the chopper feed rolls to provide a smooth material flow. If the snapping rolls were allowed to overrun the feed rolls, the stalks would buckle and enter the chopper cylinder diagonally which would result in long cuts and reduced chopper performance. An aggressive roll was required for more positive feeding and to remove the husks, but a less aggressive roll would reduce shelling losses.

As a result of the compromises imposed on the stalk roll design, the first design involved rolls fabricated from 3 1/2 inch pipe with four 1/2 inch angle iron flutes welded parallel to the axis of the roll. Minimum clearance was 5/8 inch when the angle iron flute was at top dead center, and increased to a maximum of one inch as the flute was rotated. Timing gears kept the flutes in mesh, and a shear pin drive sprocket protected them from damage. The rolls were driven at 550 rpm which produced a feed rate slightly faster than the chopper feed rolls. The bearing end plates could be rotated as much as 30° from the vertical position as shown in Figure 20. Figure 23 illustrates the configuration of the first snapping roll design.

By enclosing the snapping rolls with sheet metal, the shelled corn was saved, so butt shelling due to aggressive rolls could be tolerated in return for a more positive feeding action and reduced amount of trash conveyed to the sheller.

A three bar feeder paddle was positioned between the row crop gathering belts and the snapping rolls for the purpose of conveying the stalks butt first into the snapping rolls and also to help transfer the snapped ear into the cross auger. The feeder paddle was driven at 240 rpm to slightly overrun the feed rate of the snapping rolls. Figure 24 shows the feeder paddle design, and Figures 20 and 25 illustrate its position within the snapping unit frame. Figure 33 depicts the function of the feeder paddle, and Figure 34 lists the rotational speed of each machine component.

An auger was installed below the snapping rolls to convey the snapped ears away from the rolls, and a deflector shield was positioned above the rolls to prevent stalks from passing over them. The completed snapping unit is illustrated in Figure 26.

Figure 27 shows the snapping unit in position for mounting on the chopper. The unit is shown attached to the chopper with four mounting pins in Figure 28, and the row crop head has been attached to the snapping unit with four more pins as illustrated in Figure 29. Figure 30 is a front view into the throat of the snapping unit to portray the position of the gathering belts, feeder paddle, and snapping rolls; and also to depict the location of the deflector shield. The schematic in Figure 33 illustrates the function of each machine component.

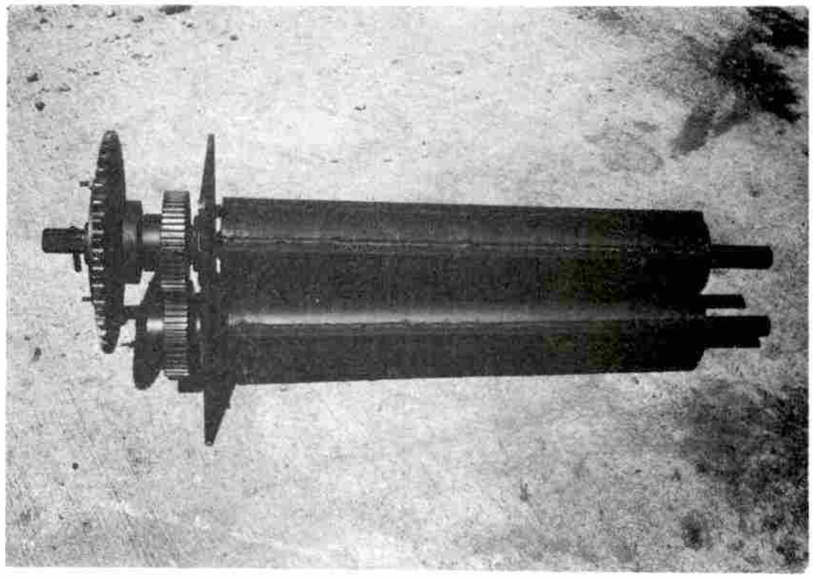


Figure 23. First design of horizontal snapping rolls with timing gears and shear pin drive sprocket

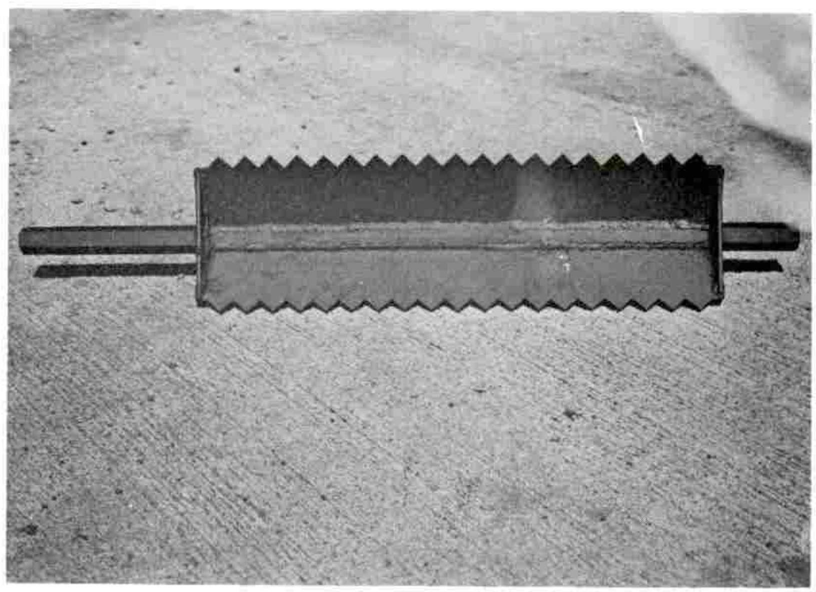
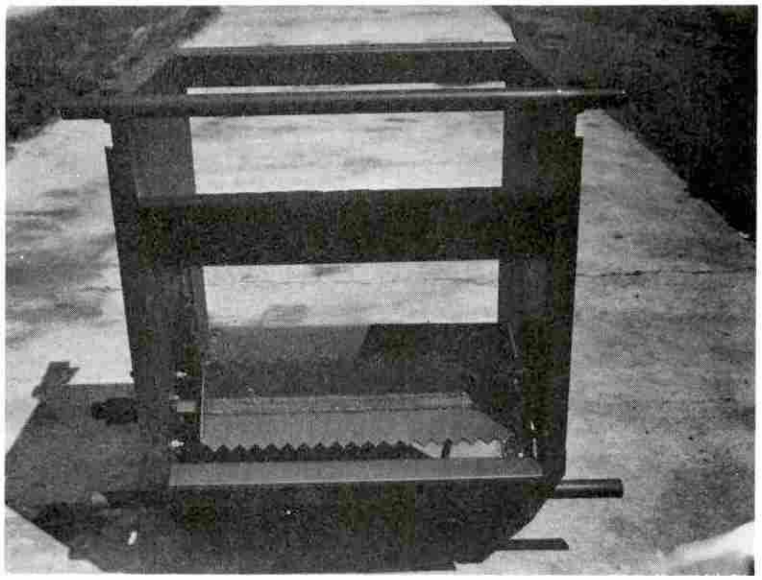


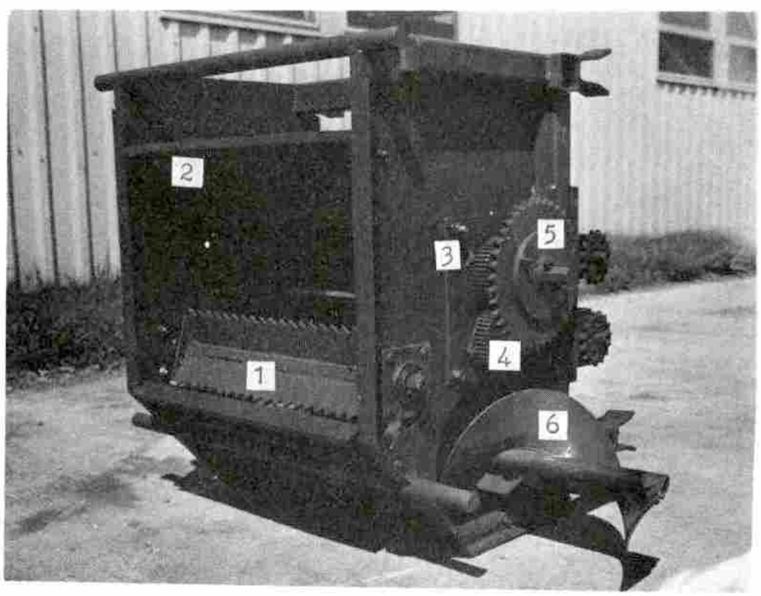
Figure 24. Feeder paddle designed to convey the stalks from the gathering belts to the snapping rolls

Figure 25. Feeder paddle installed in the snapping unit frame (front view)

Figure 26. Assembled snapping unit (front view)

1. Feeder paddle
2. Deflector shield
3. Bearing end plate
4. Timing gears
5. Shear pin sprocket
6. Cross auger




2
3
5
4
1
6

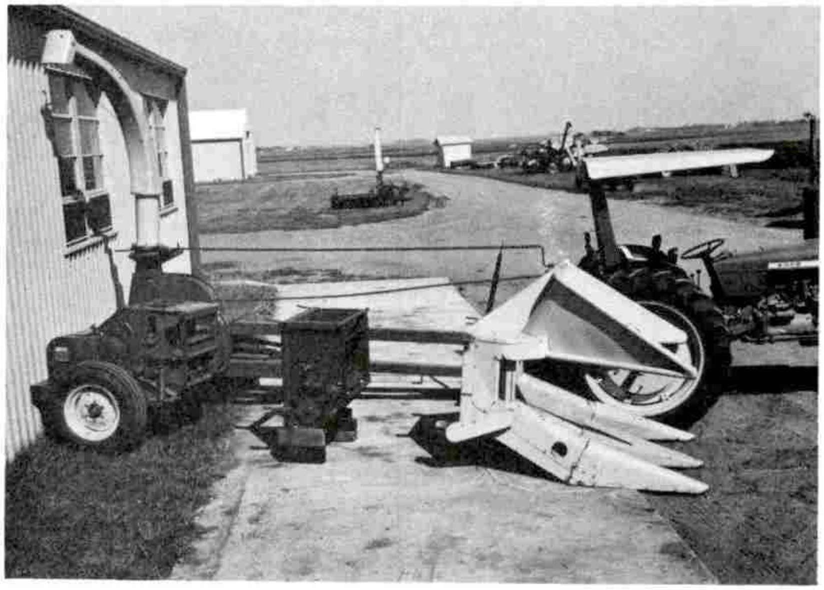


Figure 27. Snapping unit in position for attachment to the chopper

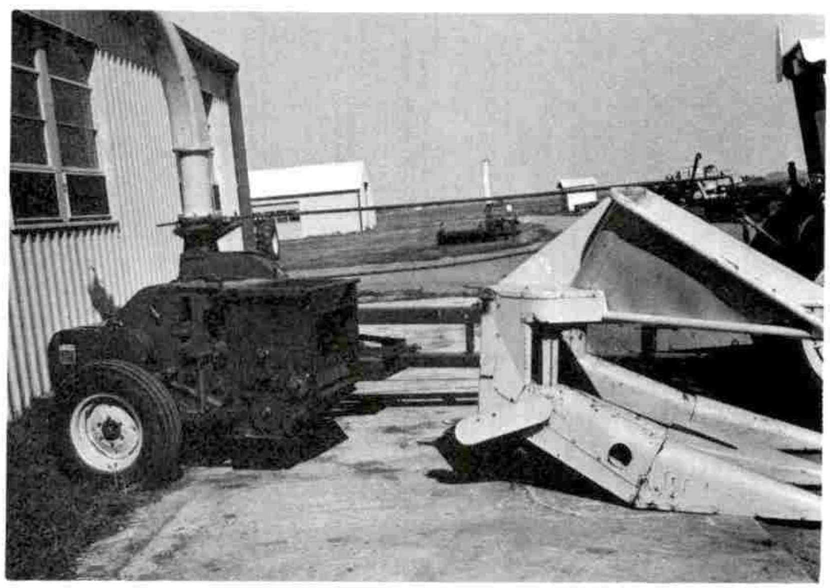


Figure 28. Snapping unit attached to chopper

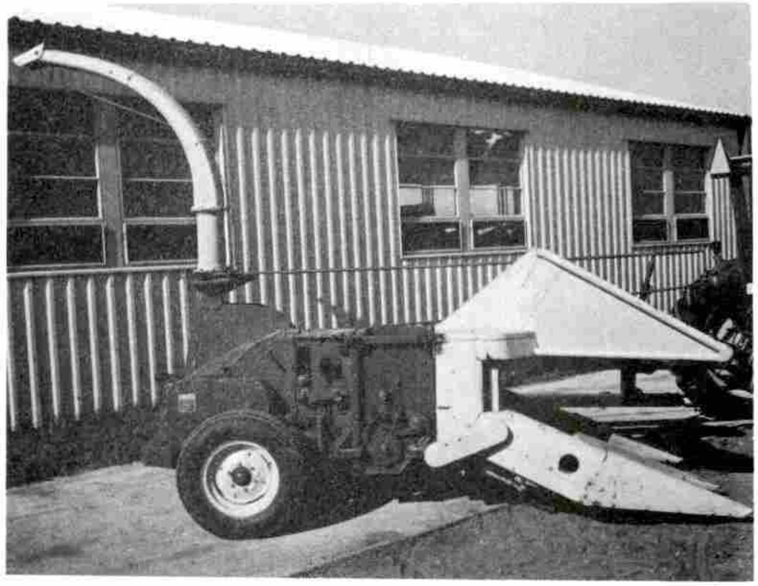


Figure 29. Snapping unit mounted between the row crop head and the chopper

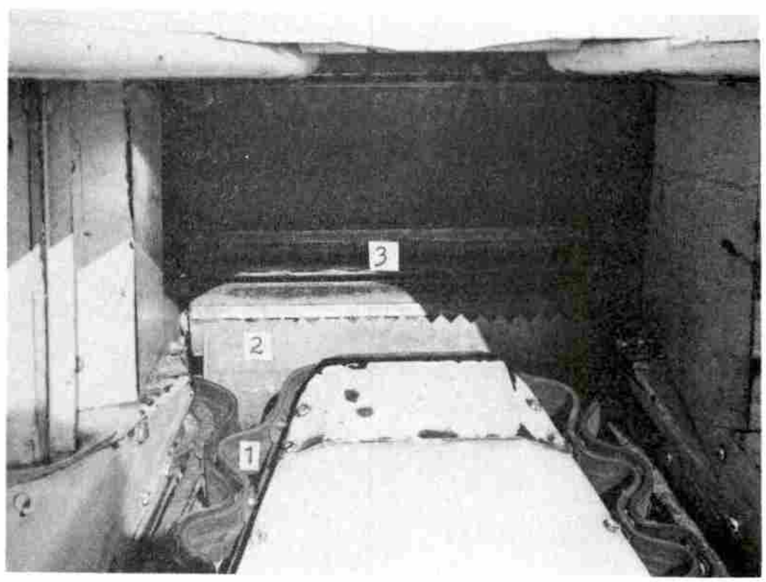


Figure 30. Front view into the throat of the snapping unit
1. Gathering belts
2. Feeder paddle
3. Snapping rolls

A sheller was designed to attach to the harvester to provide the option of collecting ear corn or shelled corn. A two-row capacity compact sheller capable of shelling wet corn was needed. A four-row capacity cage sheller was selected in order to provide capacity for the amount of trash anticipated. A commercial sheller with the required dimensions could not be found so a unit was fabricated from the parts of a New Idea #729 uni-sheller. The nine-inch diameter by 49 1/2 inch long rotor and 15 inch diameter cage were shrouded with sheet metal to form the basic cage sheller. A five inch cross auger was added to convey the shelled grain to the rear elevator. Power was obtained through a number 80 roller chain drive from the cutter head shaft of the chopper. A safety clutch sprocket was used on the sheller for overload protection. The sheller was positioned above the chopper such that the cobs, husks, and trash discharged from the sheller were gravity fed into the chopper cutter head to be chopped with the stalks.

The cage sheller was mounted on a frame cantilevered from the snapping unit so that the entire assembly was an integral unit which could be removed from the chopper by removing four mounting pins. Figures 31 and 32 illustrate the position of the cage sheller on the finished machine.

A 14 inch Grain-O-Vator auger was attached to the snapping unit to convey the ear corn from the snapping rolls to the cage sheller. A swivel head on the auger provided the option of by-passing the sheller and dumping ear corn directly into the rear elevator thus collecting either shelled corn plus refuse ensilage or ear corn plus stover ensilage.

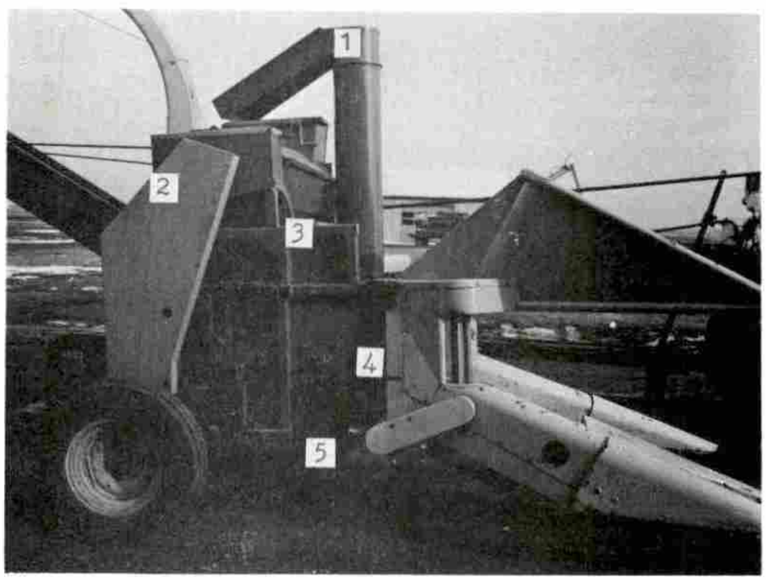
Figure 31. Side view of completed Beefmaker II

1. Vertical ear corn auger
2. Cage sheller
3. Grain elevator

Figure 32. Beefmaker II (without chain shield)

1. Swivel spout
2. Sheller drive
3. Cantilevered sheller mounting
4. Beater paddle drive chain
5. Cross auger drive chain


1
2
3


1
2
3
4
5

The final machine, Beefmaker II, weighed 4,500 pounds of which 1,500 pounds was credited to the experimental snapper-sheller attachment. Figures 31 and 32 identify the components on the completed machine.

The only modifications to the original chopper were the addition of two sprockets to the drive line, the row crop head drive chain was lengthened, and an idler sprocket was bolted to the chopper frame.

Field Testing

Field tests were conducted to evaluate the functional performance of the Beefmaker II. The tests were started early in the fall when the grain was still above 35 percent moisture content in order to permit time for design modifications. Wet corn required more snapping energy so four more flutes were welded on each snapping roll to increase their aggressiveness. After the corn dried to below 28 percent moisture content, a less aggressive snapping roll design was tested in an attempt to reduce shelling losses due to snapping. Those rolls utilized a smoother surface geometry and a smaller clearance, and significantly reduced the shelling losses. The larger bottom roll improved the gathering function of the snapping rolls and prevented stalks from feeding into the ear corn cross auger located below the snapping rolls. Figure 35 compares the two snapping roll designs and Table 17 outlines the shelled corn losses in the refuse.

Further snapping roll testing indicated that positioning the horizontal rolls vertically in line with one another resulted in the optimum snapping

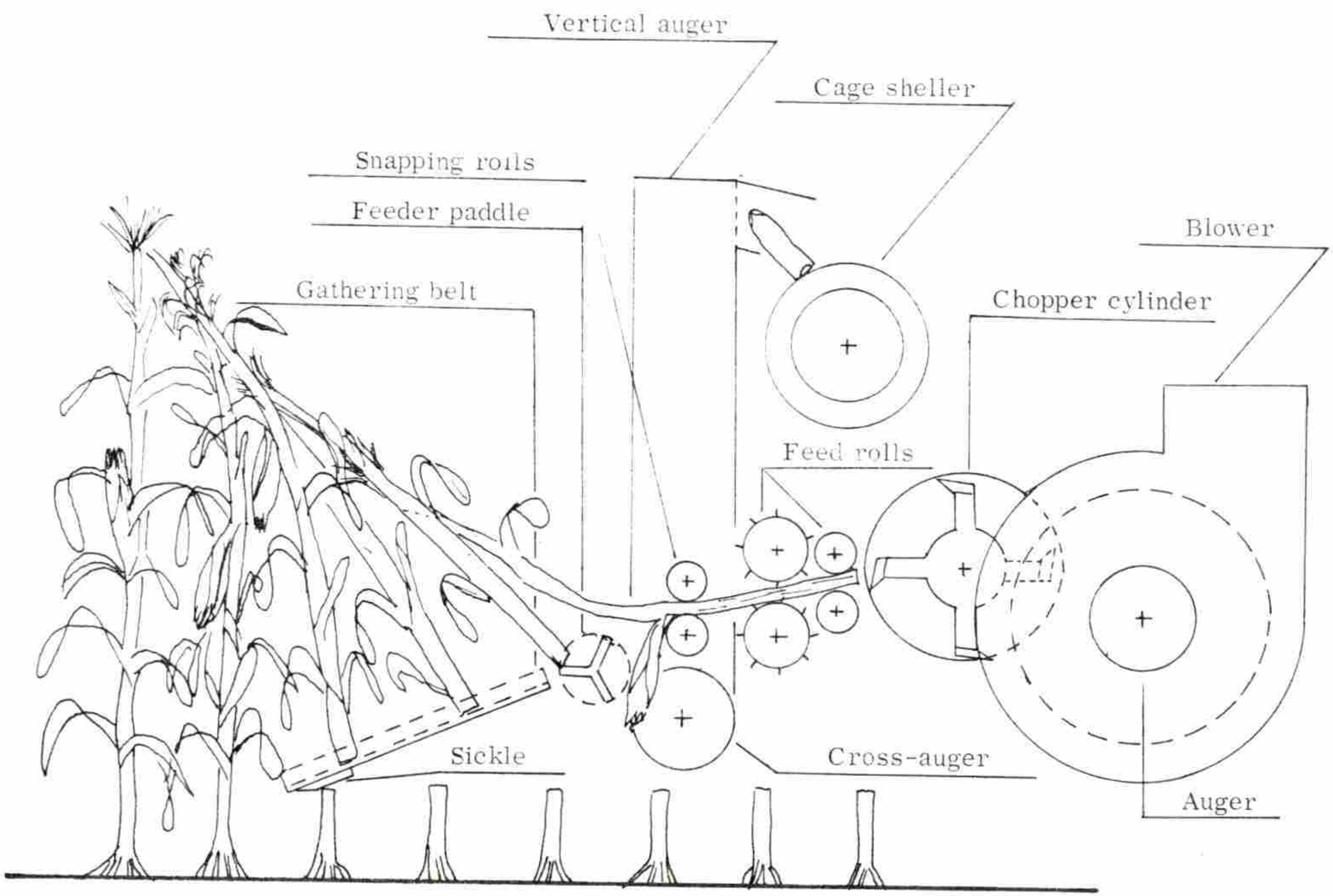


Figure 33. Schematic of the functioning components of the Beefmaker II

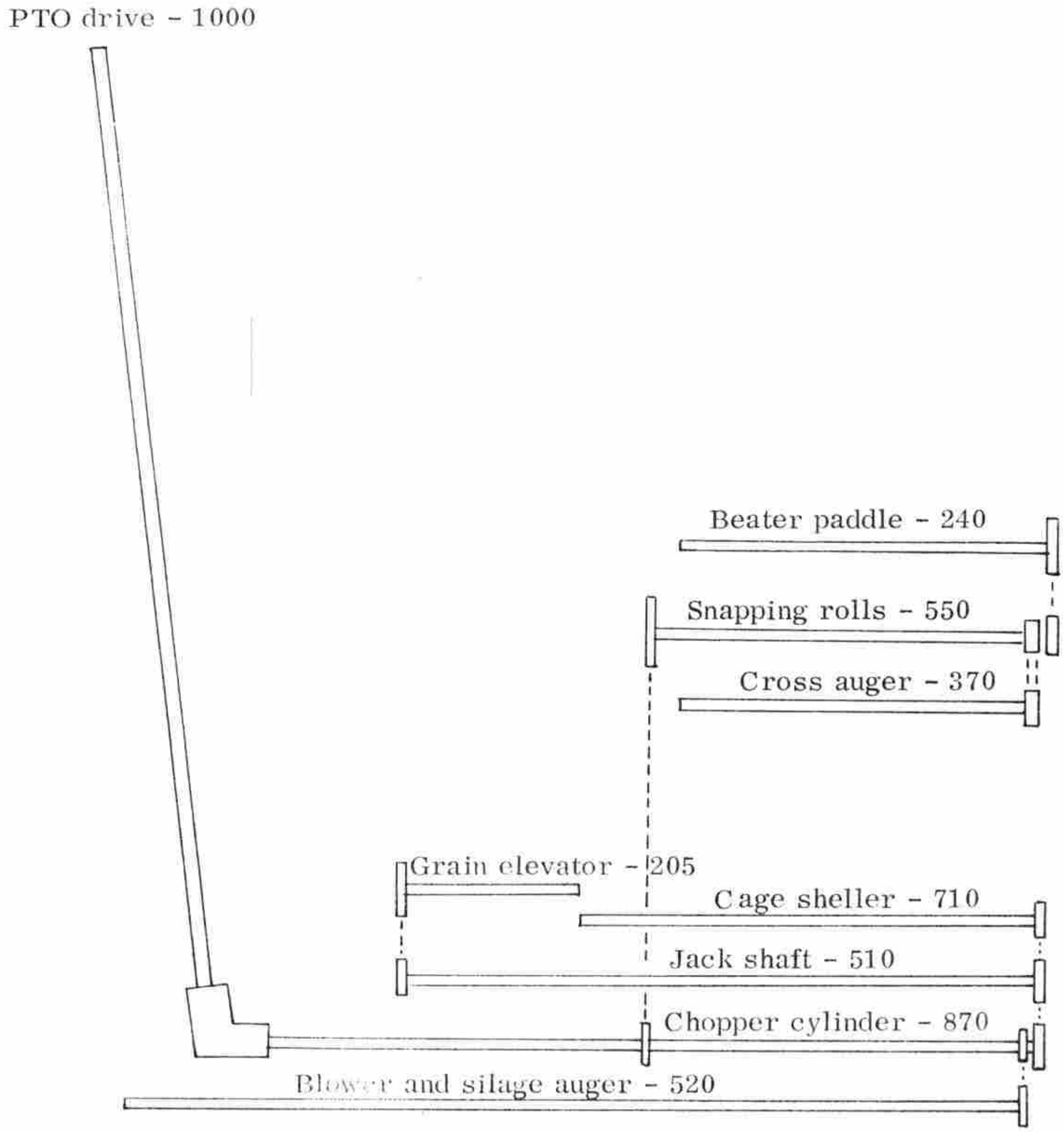


Figure 34. Rotational speed in rpm of components in Beefmaker II (top view)

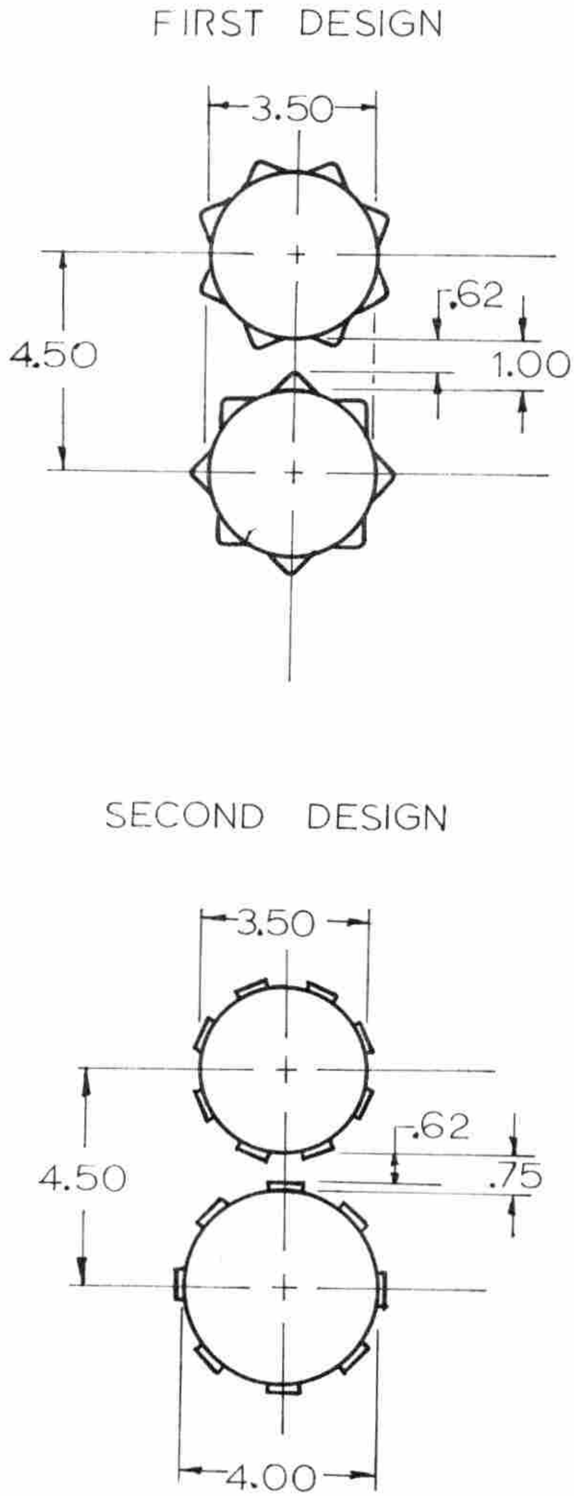


Figure 35. Horizontal snapping roll designs for Beefmaker II

performance. When the top roll was rotated forward of the bottom roll, it helped to accelerate the snapped ears downward into the cross auger, but it also permitted many of the unsnapped stalks to pass underneath and fall directly into the cross auger. The same problem was experienced when the feeder paddle was lowered 1 1/4 inches. Refer to Figure 20 and 33 for the relative position of the functioning components.

The snapping roll speed was reduced to 425 rpm for a brief field test, but the feeding efficiency was marginal at that speed.

Field losses were incurred in several areas. Shelled corn in the refuse resulted from snapping losses that were not separated from the foliage, and from sheller losses which were deposited at the cutter head to be included with the refuse.

The amount of shelled corn measured in the refuse is recorded in Table 17. The losses were measured by collecting the refuse from the chopper discharge spout for 1/100 of an acre. That volume of material was first reduced with a grain combine which had previously reached equilibrium for refuse separation. Final separation was accomplished with a water bath method. The grain, having a specific gravity greater than one, sank in water while the refuse floated to the surface. The water bath method was very thorough and even removed the grain chips from the refuse.

Small shelled corn losses in the refuse may not be serious because recent feeding trials indicated that some corn was needed in the refuse to meet the minimum energy requirement of beef cows.

Shelled corn losses on the ground occurred when shelled corn from the snapping process was entrapped in the husks until they were vibrated by the feed rolls at which time some of the shelled corn was released and escaped down between the front and rear feed rolls. This loss could have been minimized by enclosing the area under the chopper feed rolls.

Ear corn losses on the ground were negligible when the crop was harvested above 28 percent grain moisture content.

One of the major problem areas was the vertical auger used to elevate the ears to the sheller. Trash would accumulate in the 90° elbow at the bottom of the auger and restrict the flow of material. An auger was used because it was readily available and was inexpensive, but its performance proved to be unsatisfactory for that application. The auger and elbow are illustrated in Figure 36.

The gravity flow discharge chute which returned the sheller trash to the chopper cutter head did not always function, especially in wet corn. Material would lodge in the narrow section of the chute and accumulate until the flow was completely restricted. A small beater paddle would have eliminated the problem. Figure 37 shows the discharge chute as it was mounted on the machine.

The sheller did not include a fan nor a cleaning system so the shelled corn contained some trash. The product was suitable for ensiling as high moisture feed, but it was not acceptable for artificial drying; however, a fan could have been added to remove most of the foreign material.

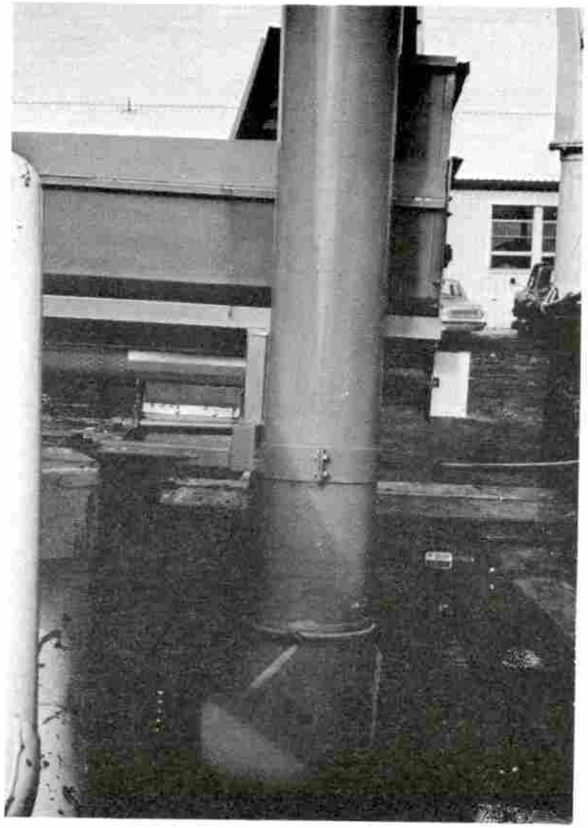


Figure 36. Vertical auger and 90° elbow

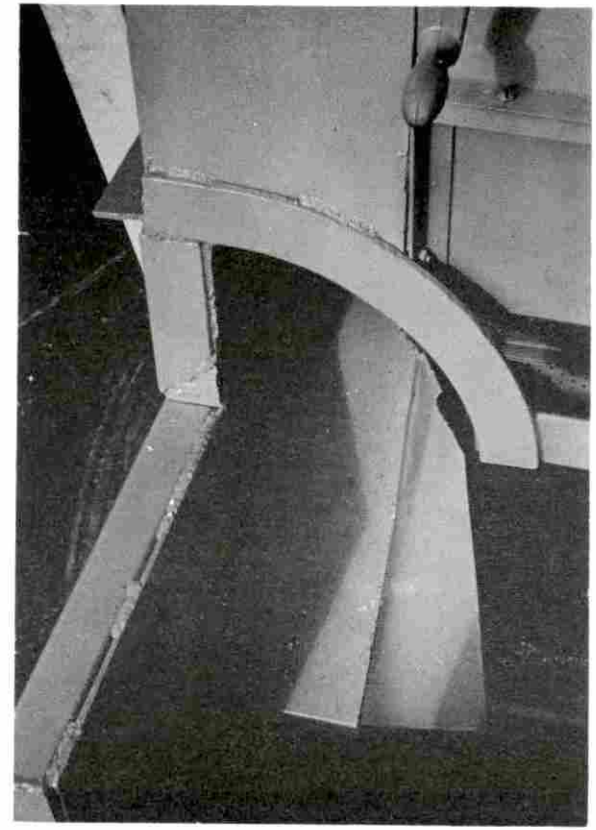


Figure 37. Discharge chute used to return the sheller trash to the chopper cylinder

Table 17. Measured shelled corn losses in refuse from Beefmaker II

Situation[a]		Plot size, acre	Losses bushels/acre	Weight ratio[b] Grain: refuse[c]
		First snapping roll design[d]		
Run 1	2 mph	0.0100	11.0	1:9.7
Run 2	2 mph	0.0100	12.6	1:8.5
Run 3	2.5 mph	0.0100	12.9	1:8.3
Run 4	3.0 mph	0.0100	17.4	1:6.2
	Average		13.5	1:8.2
		Second snapping roll design		
Run 1	2.6 mph	0.0100	2.30	1:46.6
Run 2	2.6 mph	0.0100	1.97	1:54.4
Run 3	2.6 mph	0.0688	4.81	1:22.3
Run 4	2.6 mph	0.0688	6.39	1·16.8
Run 5	3.0 mph	0.0100	8.70	1:12.3
	Average		4.83	1:30.5

Shelled corn loss on the ground = 3.2 bushels/acre

[a]Corn yield of approximately 100 bushels/acre of grain and three tons/acre of refuse

[b]Pounds of 15.5 percent moisture content shelled corn per pound of 50 percent moisture content refuse

[c]Separated with water bath method

[d]The cross auger was partially plugged and may have contributed to these losses

The capacity of the Beefmaker II depended on the field conditions and the power unit used. Two rows of 120 bushel/acre corn were harvested at 2 to 2 1/2 mph with an 80 hp tractor. However, if a recutter screen were used and the fields were soft, 90-100 hp would be required to adequately power the machine at 2 1/2 mph. A speed of 3 1/2 mph was obtained during power tests, but the 92 hp tractor lugged down before the machine capacity was exceeded. An investigation with high speed photography suggested that the machine was near its maximum capacity at that speed. All tests were conducted in corn hybrids selected for combine harvesters, so the field capacity would be expected to decrease in rank silage hybrids.

The preferred method of collecting the products from the Beefmaker II involved trailing a wagon behind the harvester to collect the shelled corn and using a second tractor to pull the forage wagon beside to collect the refuse.

Figures 38, 39, and 40 show the Beefmaker II in field operation.

Discussion

The Beefmaker II experimental total corn harvester successfully harvested the entire corn plant and separated it into grain and stalk components. Most of the design objectives were satisfied, but modifications are required to meet others.

The forage harvester concept offered several distinct advantages. It was capable of performing three different harvesting operations, namely whole plant

Figure 38. Beefmaker II in field operation

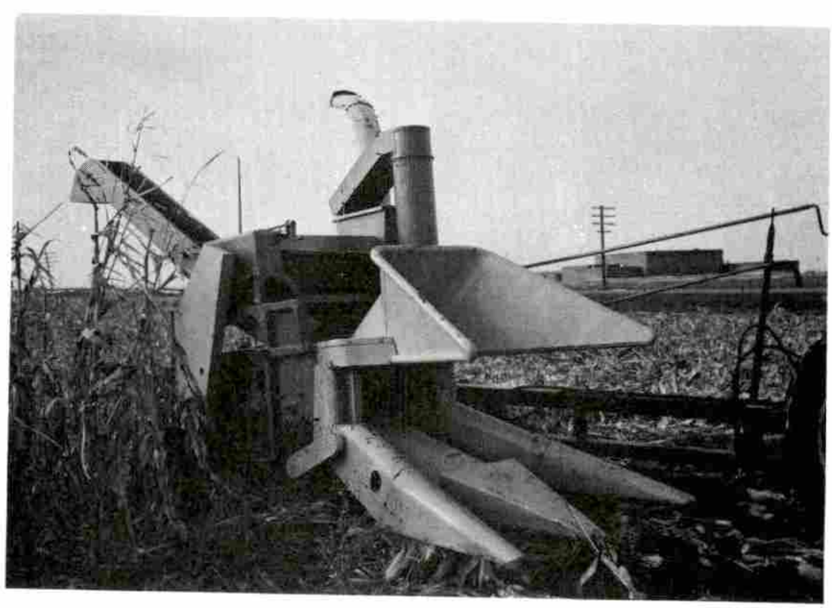


Figure 39. Front view of Beefmaker II during field functional testing

ensilage harvest, total harvest for ear corn and stover, and total harvest for shelled corn and refuse. Capacity was greater than for any commercial total harvester developed to date. The machine was simple and compact, and it offered some economic advantages due to its adaption as an attachment to an existing machine. Many farmers own a forage chopper for their present farming system, and the purchase of a 1,500 pound attachment to enable them to total harvest would be inexpensive compared to many of the proposed systems. The enclosed snapping rolls minimized field losses and permitted the use of more aggressive rolls to snap the corn cleaner.

Several disadvantages were also noted in the forage harvester approach. Product collection was a big problem that has not yet been resolved. The combine systems had the advantage of collecting grain in a tank, but most forage harvester frames would not support an adequate grain tank. As a result, the operator either needed to pull two wagons--which was not feasible--or pull one and depend on another tractor and operator to collect the second product. Separation of grain from refuse was not as efficient compared to the combine systems. Most forage harvesters are pulled type machines so other machinery would be needed to open the fields. Few farmers would have the storage capacity needed to total harvest their entire corn crop, so other grain harvesting machinery would probably be needed in addition to the total harvester.

The material handling problems associated with the total corn harvesting concept are staggering. To total harvest 15 acres of corn per day would require material handling capabilities for 60 tons of wet shelled corn and 75 tons of refuse ensilage. A feedstuffs center would have to be acquired along with the total harvesting machinery to make the system feasible. The field capacity of a high volume total harvester could not be utilized if the material was not processed at the same rate.

Total harvesting offers some unique advantages, but it will not become popular until efficient and economical machinery is developed. The Beefmaker II represents one feasible system which could be used by many farmers, but other machines and other systems need to be developed and compared.

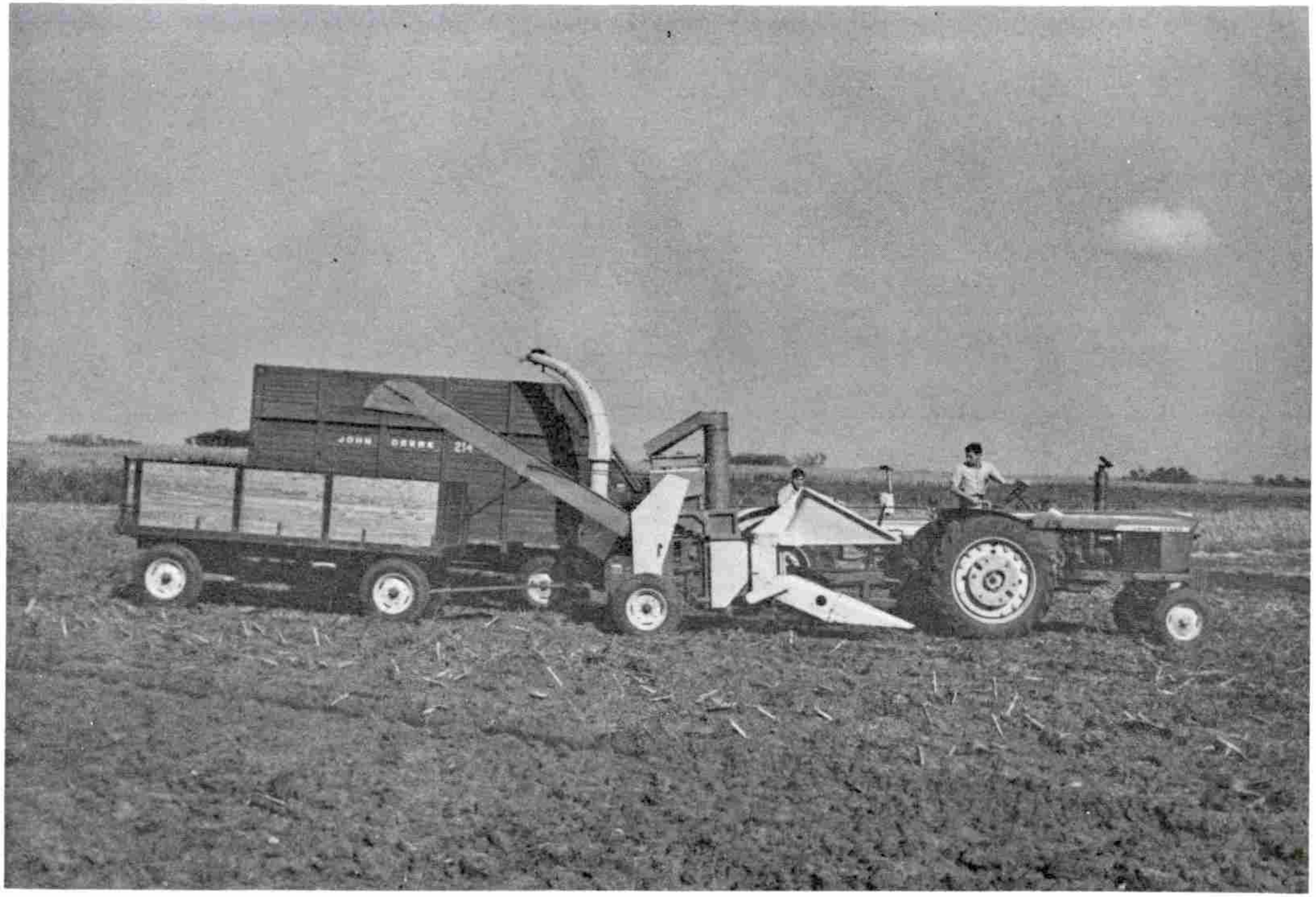


Figure 40. Beefmaker II in field operation

GRAIN - REFUSE MOISTURE CONTENT

Procedure

The relationship of grain moisture content to refuse moisture content for five different hybrids was studied. This relationship was of interest in selecting a "dry grain - wet stalk" combination that would best fit a total corn harvesting system. Current technology suggests it is desirable to harvest the grain when the moisture content is below 30 percent in order to minimize damage to the kernels and to minimize drying costs. However, the refuse should be harvested while it is still above 48 percent moisture content because it makes a more palatable feed, it requires less energy to chop, and it incurs fewer storage problems (45, 61). The wetter refuse ensilage is more dense and compacts better thus reducing spoilage, and it is more apt to complete the fermentation process than the dry ensilage. Thus a compromise must be reached between the grain and refuse moisture contents unless a hybrid inherently possesses the correct balance.

A 5 x 5 Latin square design was chosen to investigate corn moisture relationships and the 25 plots were planted with five hybrids on a total area of 1 1/2 acres. The following common hybrids were selected:

Hybrid 1	Trojan TXS102	102 days relative maturity
Hybrid 2	Pioneer 3570	114 days relative maturity
Hybrid 3	Pioneer 3545	116 days relative maturity
Hybrid 4	Pioneer 3505	120 days relative maturity
Hybrid 5	Pioneer 3369	125 days relative maturity

The plots were planted on May 2, 1968, at the rate of 22,000 to 24,000 plants per acre, and each plot received identical treatments. At maturity, five stalks were taken at random from each plot and analyzed for moisture content at five different sampling dates. The corn was shelled from the stalk and the stalk, leaf, husks, and cob were chopped into one inch lengths. For each plot, the grain and the refuse of the five stalks were bulked and one moisture content determination was made for the grain and one for the refuse. A wide range of maturity between individual plants was common in each plot so by randomly selecting and combining five plants from each plot, an average moisture content was determined and variability was reduced.

Five moisture determinations were made for each hybrid over a period of six sampling dates. That irregularity occurred because rain interrupted the collection of sample two. Table 18 lists the sampling dates for each hybrid.

Table 18. Dates of sampling for each hybrid in experimental design

Sample no.	Date	Coded dates[a]	Hybrids sampled
1	September 18	1	1, 2, 3, 4, 5
2	September 25	2	1, 2
3	October 2	3	1, 2, 3, 4, 5
4	October 16	5	1, 2, 3, 4, 5
5	October 23	6	3, 4, 5
6	October 29	7	1, 2, 3, 4, 5

[a]Coded dates are weeks from September 11

During the moisture sampling, two 90-foot rows in each plot were untouched and those were harvested on the final sampling date to determine grain and refuse yields. The grain yield was obtained from 1/103 acre by harvesting with a combine and weighing the grain in a strain gaged weigh box suspended in the grain tank. Dropped ears were collected and included in the sample to eliminate error due to preharvest losses. A slight error in the recorded yields was incurred due to losses over the combine sieve, but the effect of this error was minimized by harvesting slowly and by employing the same method for each plot. The grain yields were then corrected to a 15.5 percent moisture basis and were also adjusted for the difference in plant population.

The refuse yield was obtained from 1/1000 acre by collecting the discharge from the combine plus the above ground portion of the stalks. This material was then weighed on a spring scale and converted to dry matter weight.

Results

The yield data were programmed on OMNITAB and were statistically analyzed by the computer for a Latin square and a covariance analysis. The Latin square analysis of variance tables for the grain and refuse yields are shown in Tables 19 and 20 respectively. The results indicated that the effect due to rows and columns was not significant at the five percent level, so the assumption of homogeneous soil conditions and equal treatments was valid. For both the grain yield and the refuse yield, the effect due to different hybrids was significant at the five percent level.

Table 19. ANOV of grain yields for a Latin square design

Source	df	Sum of squares	Mean square	F
Rows	4	614.863	153.716	1.334
Columns	4	289.295	72.324	0.627
Hybrids	4	2649.456	662.364	5.746*
Error	12	1383.179	115.265	
Total	24	4936.793	205.700	
Tabulated F = 3.26				

*Significant at five percent level

Table 20. ANOV of refuse yields for a Latin square design

Source	df	Sum of squares	Mean square	F
Rows	4	0.230	0.058	0.369
Columns	4	1.040	0.260	1.668
Hybrids	4	2.074	0.518	3.325*
Error	12	1.871	0.156	
Total	24	5.215		
Tabulated F = 3.26				

*Significant at five percent level

Table 21. Analysis of covariance of grain yields with the covariate plant population

Source	df	Sum of squares	Mean square	F
Rows	4	398.363	99.591	1.592
Hybrids	4	831.699	207.925	3.324*
Error	15	938.266	62.551	
Tabulated F = 3.01				

*Significant at five percent level

Table 22. Analysis of covariance of refuse yields with the covariate plant population

Source	df	Sum of squares	Mean square	F
Rows	4	0.312	0.075	0.399
Hybrids	4	2.138	0.534	2.826
Error	15	2.837	0.189	
Tabulated F = 3.01				

Since the final plant population was not the same for each plot, an analysis of covariance was conducted in order to adjust the yields for this variable. The analysis of covariance shown in Tables 21 and 22 indicated that the grain yield was influenced by the plant population, but the refuse yield was not significantly affected at the five percent level. The range of plant populations for the plots included in the experiment was relatively narrow so a constant refuse yield was expected for each hybrid. For more extreme population levels, the light energy utilized and nutrients recovered from the soil would begin to affect refuse yields. Each of the five hybrids could be planted at a population to optimize grain yields, and the resulting refuse yields would approximate the optimum for that particular hybrid.

Since the refuse yield only varied between hybrids and not with plant population, the Latin square analysis was sufficient. However, the grain yield was a function of population so an analysis of covariance was preferred.

The large F value in Table 23 indicated that the variation in plant population between plots was not random, but rather was associated with the hybrids. These variations were primarily due to lack of precision in the planting rate rather than genetic differences between the hybrids, so the yields were adjusted for population. The following equation was used to adjust the grain yields for population differences.

$$y_{adj} = y_i - B(\overline{X}_i - \overline{X})$$

Where: y_{adj} = adjusted grain yield

y_i = unadjusted grain yield for the i^{th} hybrid

B = regression coefficient

$\overline{X}_i$ = average plant population for the i^{th} hybrid

$\overline{X}$ = overall average population

Table 23. ANOV of the covariate plant population

Source	df	Sum of squares	Mean square	F
Rows	4	28363168.000	7090792.000	3.873
Hybrids	4	119347040.000	29836752.000	16.297*
Error	16	29292464.000	1830779.000	
Total	24	177002672.000		

Tabulated F = 3.01

*Significant at five percent level

Table 24 compares the grain yields as measured and as adjusted for the covariate plant population. Hybrid 3 initially had a high yield but had the lowest yield after adjusting for plant stand. It responded well to a high population.

The moisture content data were analyzed in three parts: the grain versus date, refuse versus date, and refuse versus grain. A linear and a quadratic curve were fitted to each set of data and tested for goodness of fit on OMNITAB.

Table 24. Grain yields adjusted for plant population for five hybrids

Hybrid	Plants/acre	Measured yield	Adjusted yield
1	18,450	140.7	149.1
2	19,263	142.2	146.6
3	24,452	166.2	144.6
4	19,457	158.6	162.0
5	19,050	143.1	148.6

The fitted curve equations are listed in Tables 25 and 26. In all cases, y_1 was the grain moisture content, y_2 was the refuse moisture content, and x was the time in weeks from September 11, 1968.

The grain moisture content data were best represented by the quadratic curves as illustrated in Figure 41, 42, 43, 44, and 45. Newlin (38) and Schroeder (41) indicated a linear drying rate with time; however, climatic conditions, nitrogen level, plant population and hybrid characteristics all affect the rate of moisture loss, so deviations between experiments could be expected.

The rate of moisture loss from the refuse material varied linearily with time as illustrated in Figure 46. This may have been a curvilinear relationship later in the season, but for the period during which data were collected (down to 40 percent moisture content) the rate of moisture loss was constant. The gradient of the refuse moisture curve was steeper than the grain moisture curve, but this

Table 25. Linear regression equations for moisture content relationships

Variable	Hybrid		Linear fit[a]	40	20
	1		$y_1 = 37.36 - 2.88x$		
	2		$y_1 = 40.72 - 3.06x$		
Grain moisture content versus date	3		$y_1 = 43.97 - 3.59x$		
	4		$y_1 = 45.83 - 3.48x$		
	5		$y_1 = 42.16 - 3.45x$		
	1		$y_2 = 72.05 - 4.03x$		
	2		$y_2 = 74.56 - 3.63x$		
Refuse moisture content versus date	3	best	$y_2 = 77.15 - 4.99x$		
	4		$y_2 = 76.89 - 3.27x$		
	5		$y_2 = 79.48 - 5.15x$		
	1		$y_2 = 21.64 + 1.33y_1$	74.84	48.24
	2	best	$y_2 = 26.71 + 1.17y_1$	73.51	50.11
Refuse moisture content versus grain moisture content	3		$y_2 = 17.16 + 1.35y_1$	71.16	44.16
	4		$y_2 = 33.95 + 0.93y_1$	71.15	52.55
	5		$y_2 = 17.47 + 1.46y_1$	75.87	46.67
				73.31	48.35

[a] y_1 is the grain moisture percentage, y_2 is the refuse moisture percentage, and x is the time in weeks from September 11

Table 26. Quadratic regression equations for moisture content relationships

Variable	Hybrid	Quadratic fit[a]
Grain moisture content versus date	1	$y_1 = 39.77 - 4.51x + 0.21x^2$
	2	$y_1 = 43.38 - 4.93x + 0.23x^2$
	3	$y_1 = 46.09 - 5.13x + 0.19x^2$
	4	$y_1 = 49.18 - 5.91x + 0.31x^2$
	5	$y_1 = 45.15 - 5.63x + 0.27x^2$
Refuse moisture content versus date	1	$y_2 = 66.16 + 0.13x - 0.51x^2$
	2	$y_2 = 77.16 - 5.46x + 0.23x^2$
	3	$y_2 = 77.34 - 5.13x + 0.018x^2$
	4	$y_2 = 77.41 - 3.65x + 0.05x^2$
	5	$y_2 = 80.71 - 6.04x + 0.11x^2$
Refuse moisture content versus grain moisture content	1	$y_2 = 22.48 + 4.86\ y_1 - 0.066{y_1}^2$
	2	$y_2 = 34.64 + 0.60y_1 + 0.0097{y_1}^2$
	3	$y_2 = 7.05 + 2.07y_1 - 0.011{y_1}^2$
	4	$y_2 = 8.41 + 2.56y_1 - 0.024{y_1}^2$
	5	$y_2 = -0.82 + 2.79y_1 - 0.023{y_1}^2$

best

[a] y_1 is the grain moisture percentage, y_2 is the refuse moisture percentage, and x is the time in weeks from September 11

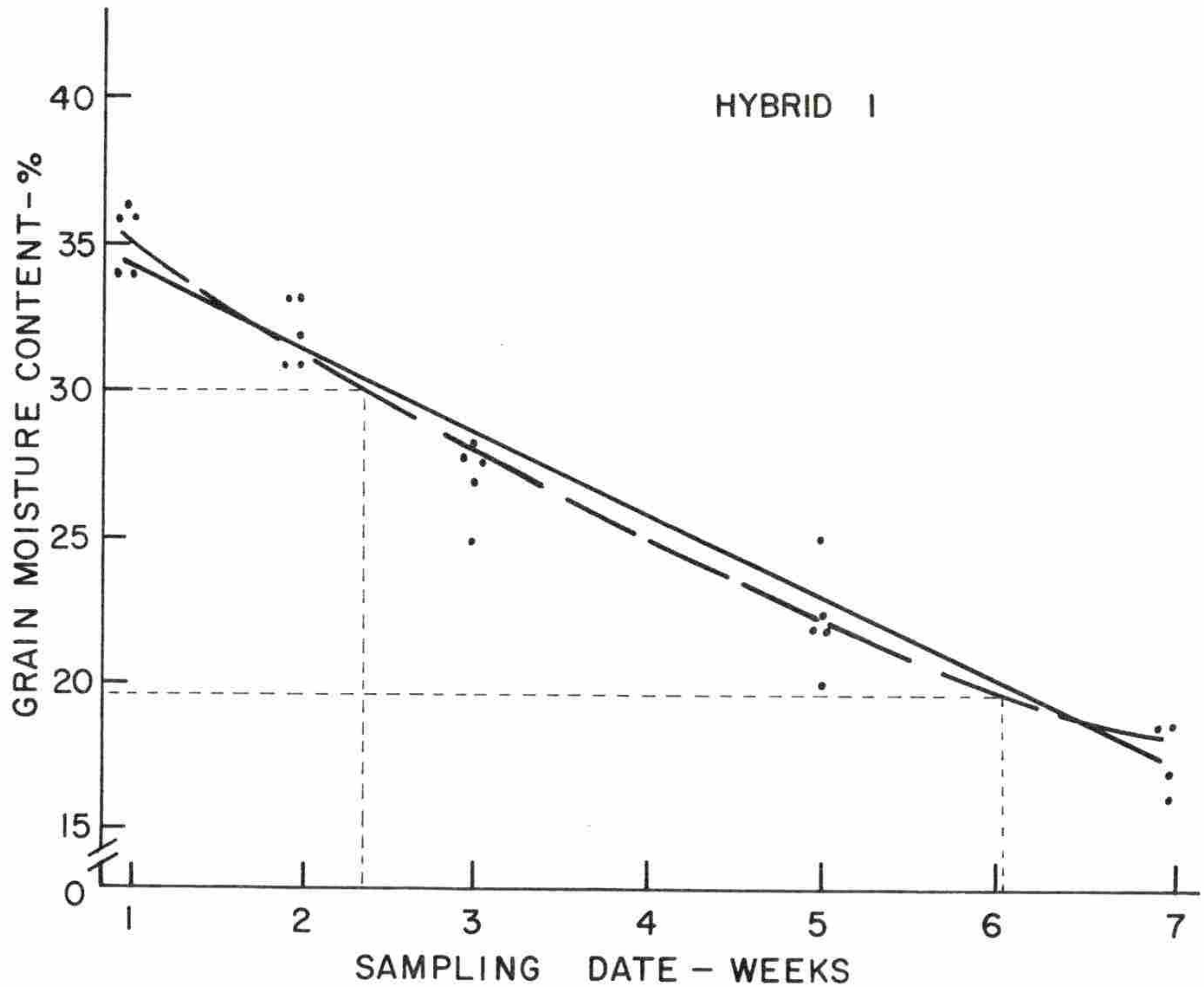


Figure 41. Linear and quadratic regressions of corn grain moisture for five sampling dates for hybrid 1

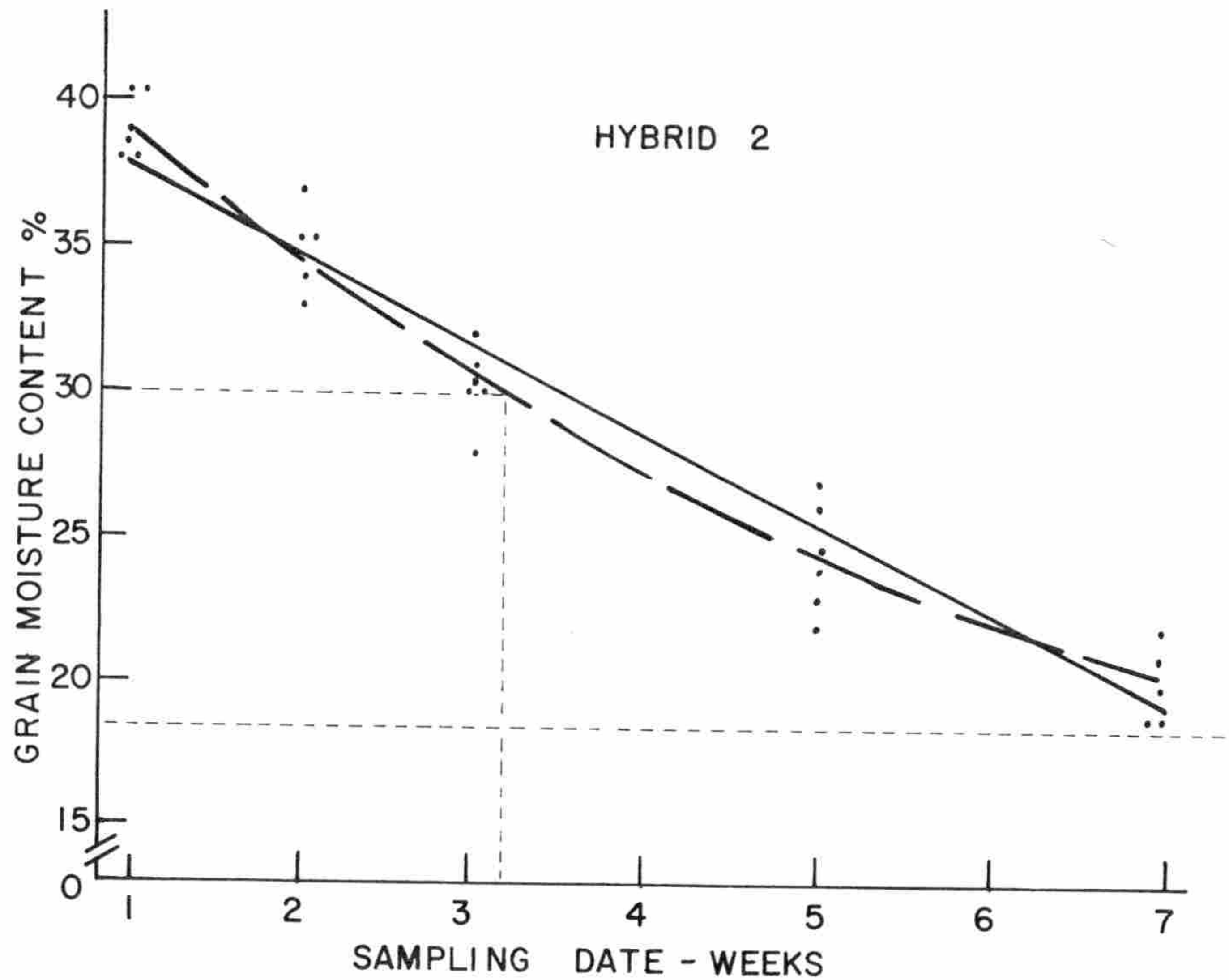


Figure 42. Linear and quadratic regressions of corn grain moisture for five sampling dates for hybrid 2

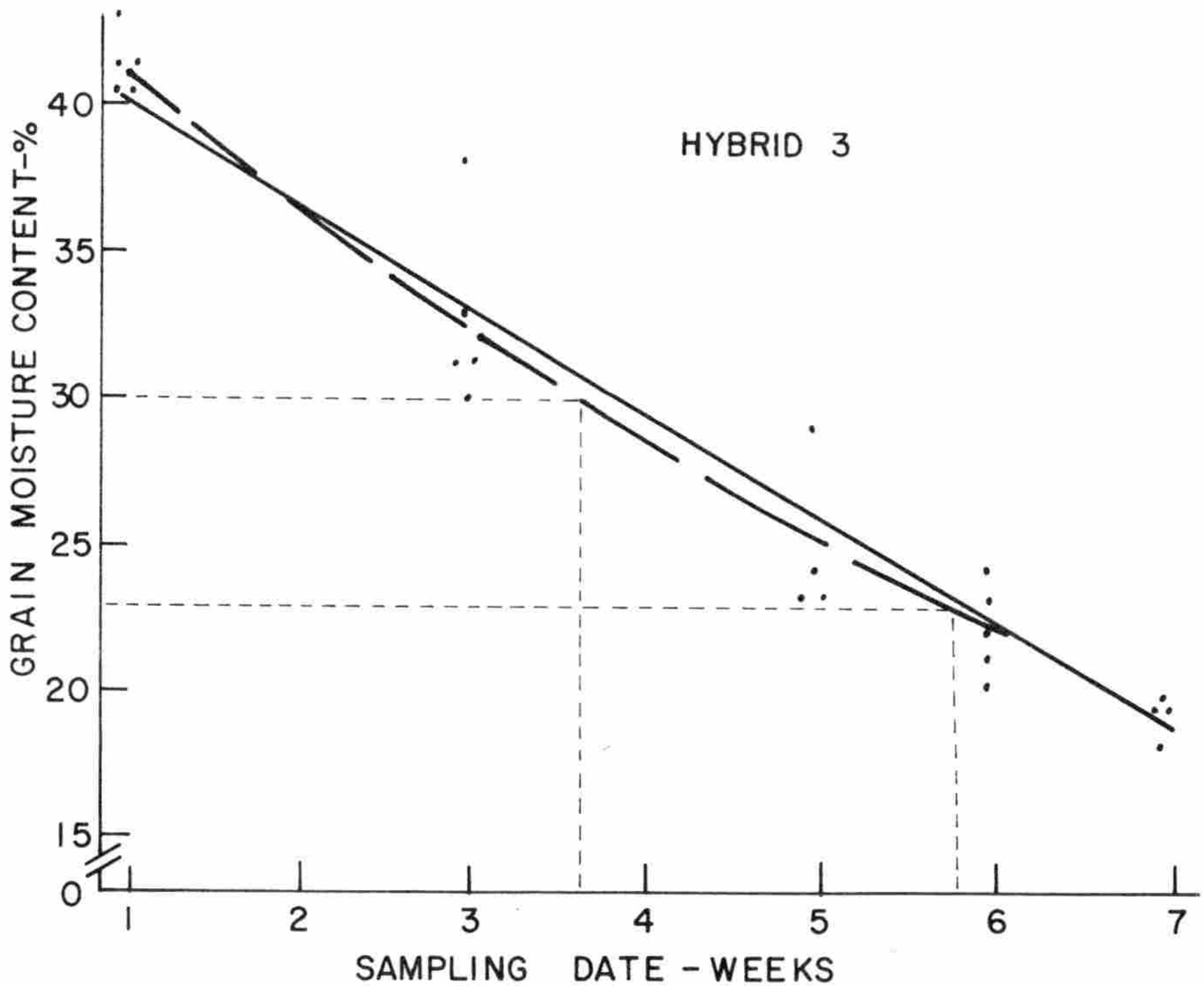


Figure 43. Linear and quadratic regressions of corn grain moisture for five sampling dates for hybrid 3

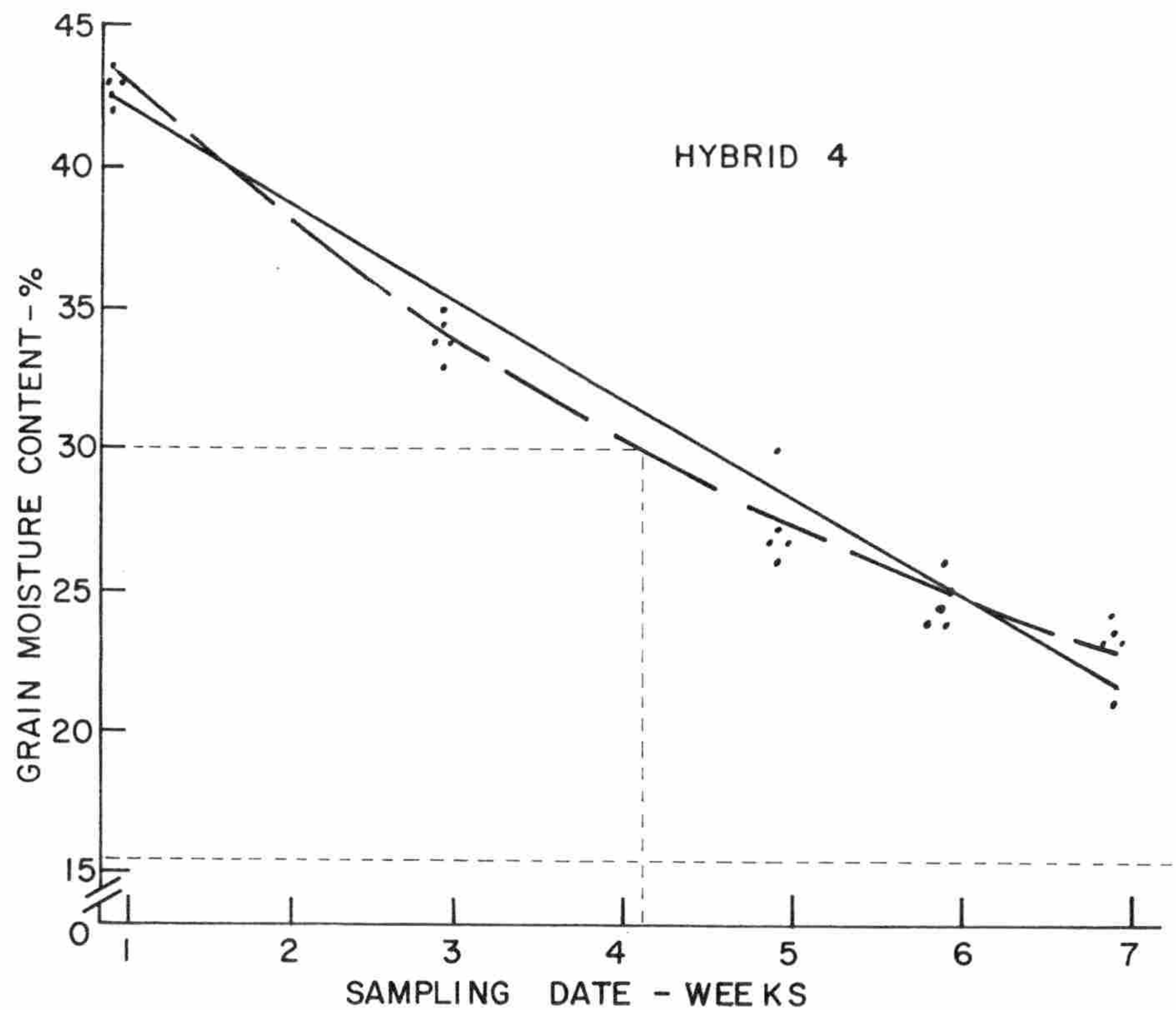


Figure 44. Linear and quadratic regressions of corn grain moisture for five sampling dates for hybrid 4

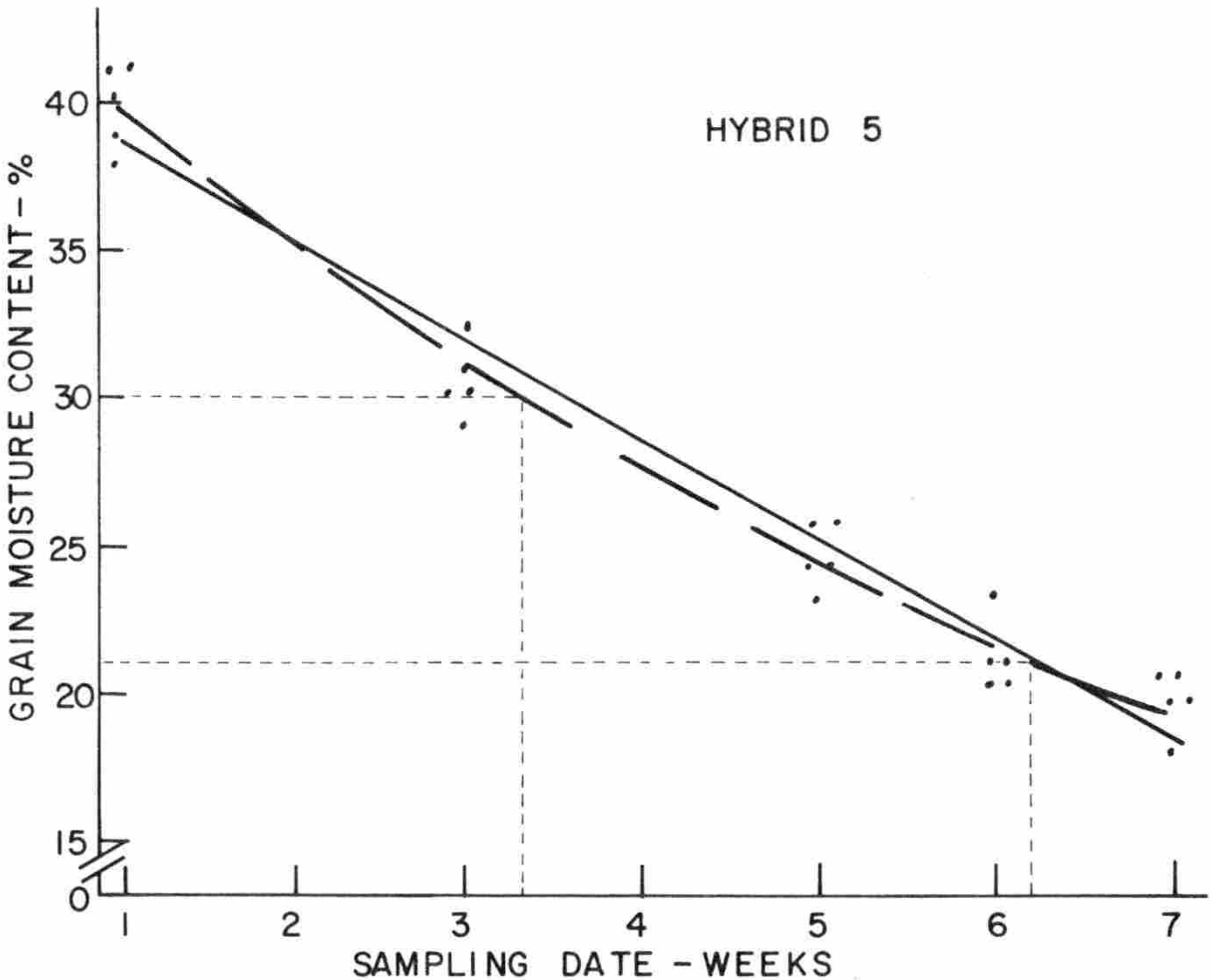


Figure 45. Linear and quadratic regressions of corn grain moisture for five sampling dates for hybrid 5

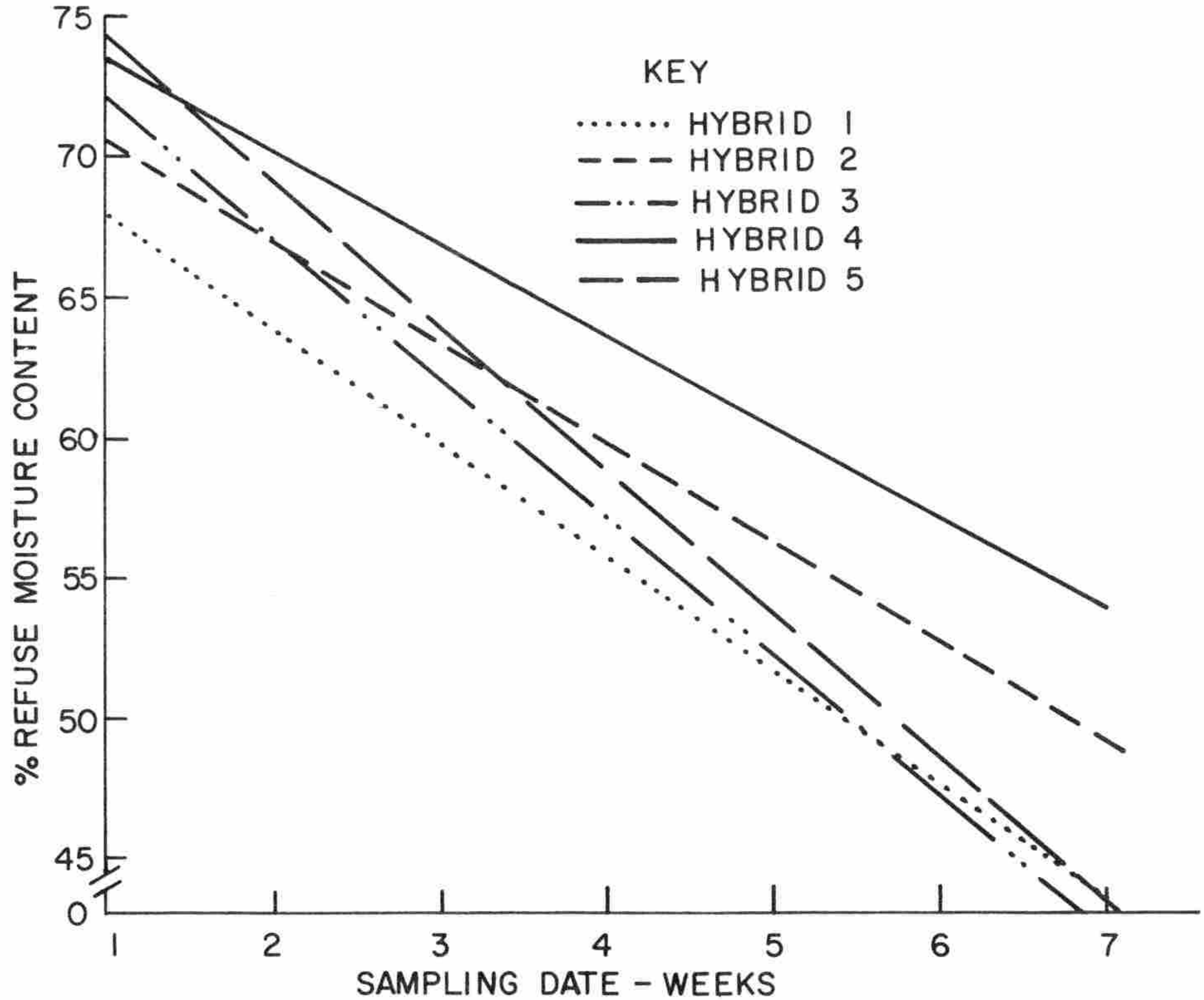


Figure 46. Corn refuse moisture content at successive sampling dates for five hybrids

was expected since the grain was protected by the husks and also had a smaller surface area to mass ratio which reduced the rate of moisture loss.

A small slope was desired for refuse, since that would permit a more uniform product and a longer harvest period. The five hybrids tested were divided into two distinct groups with hybrids 3 and 5 having similar rates of moisture loss, which were significantly higher than the other three hybrids. Both hybrids 3 and 5 were late maturing hybrids and both had fairly high plant populations, but they were only a few percentage points wetter than the other hybrids on the first sampling date. The higher rate of loss appeared to be a characteristic of the hybrid rather than a sampling variable. Grain drying rate was also high for these two hybrids.

The refuse moisture content was plotted against grain moisture content as illustrated in Figure 47. These data were well represented with the linear regression fit. A slope of zero with an intercept of 65 would be ideal because that would allow the grain to dry while the refuse remained at a constant moisture content high enough to produce good ensilage. The smaller the slope, the better the approximation of the ideal situation. The hybrids rated by order of increasing slope were 4, 2, 1, 3, and 5. The slope for hybrid 4 was significantly smaller than the others at the five percent level of probability.

A graphical technique was used to estimate the number of harvesting days available for total harvesting. An acceptable product was defined as one where the grain moisture content was below 30 percent and the refuse moisture content

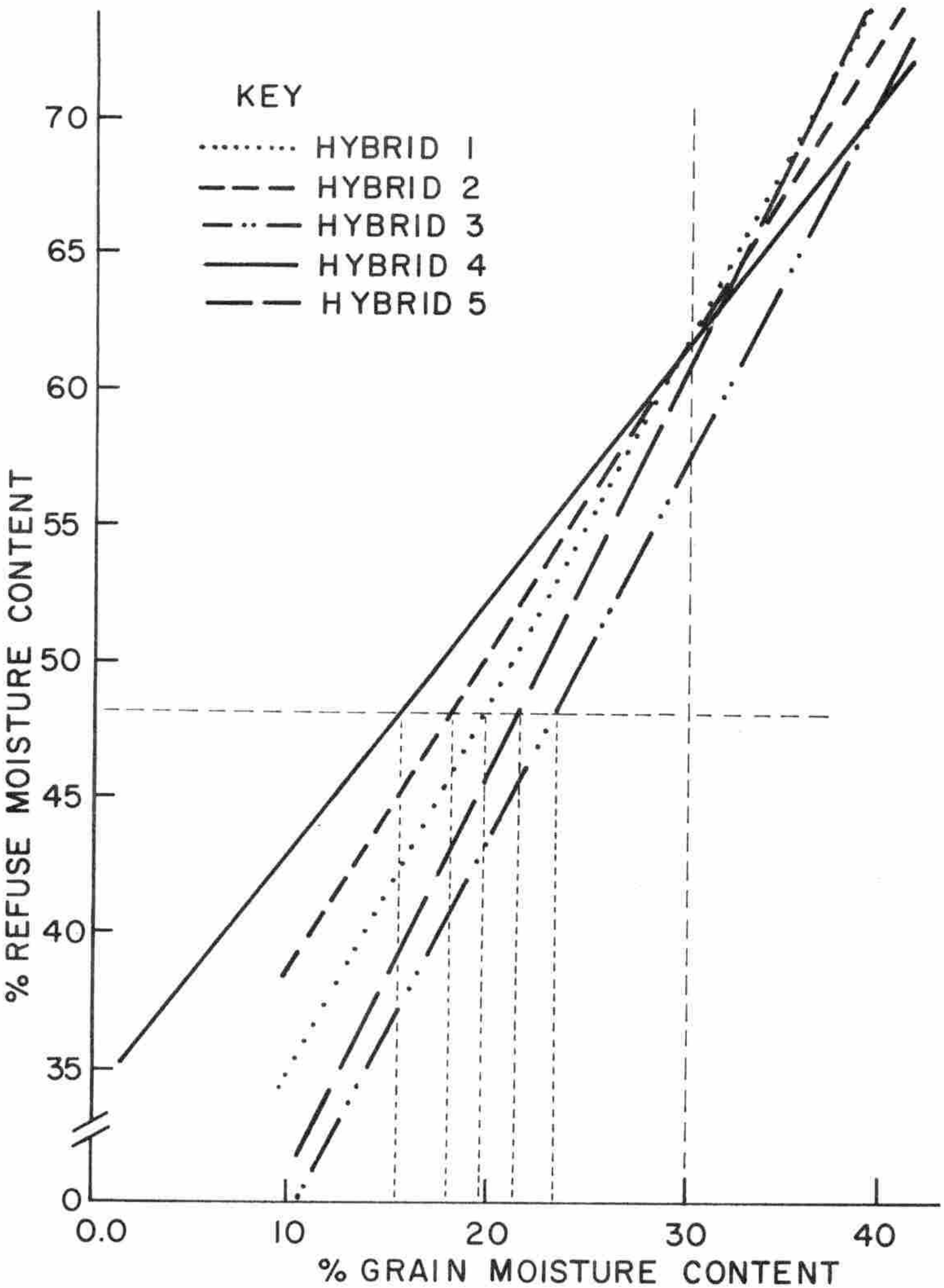


Figure 47. Moisture content relationship of corn grain and refuse for five hybrids

was above 48 percent. The grain moisture content corresponding to a refuse moisture of 48 percent was determined graphically from Figure 47, and that level of grain moisture was then transferred to the grain versus date curves in Figures 41 to 45 to determine the number of acceptable harvesting days for each hybrid. These values are tabulated in Table 27.

Discussion

An empirical equation was derived to compare the five hybrids for suitability in a total harvesting system. The following equation is only valid for comparing hybrids within a given statistical design for a given year.

$$R = K_1 \frac{G}{G_{avg}} + K_2 \frac{Y}{Y_{avg}} + \frac{K_3}{S}$$

Where: R = relative rating

G = grain yield in bushels/acre

G_{avg} = average grain yield for the hybrids compared in bushels/acre

Y = refuse yield in tons/acre

Y_{avg} = average refuse yield for the hybrids compared in tons/acre

S = slope of the refuse moisture content versus grain moisture content curve

$K_1 = 3$ = effect of grain yield on hybrid suitability

$K_2 = 1$ = effect of refuse yield on hybrid suitability

$K_3 = 1$ = effect of the moisture relationship on hybrid suitability

Table 27. Number of total harvesting days during which an acceptable product[a] was obtained for each hybrid

Hybrid	Harvesting conditions: % Moisture at starting date		% Moisture at ending date		Length of harvesting period, days
	Grain	Refuse	Grain	Refuse	
1	30.0	61.5	19.8	48.0	25.6
2	30.0	61.8	18.2[b]	48.0	35.4[b]
3	30.0	57.7	22.8	48.0	15.3
4	30.0	61.9	15.1[b]	48.0	30.0[c]
5	30.0	61.3	20.9	48.0	20.7

[a]Acceptable product defined as grain below 30 percent moisture content and refuse above 48 percent moisture content

[b]Values obtained by extrapolating the curves beyond the range of measured values

[c]Linear regression assumed for grain moisture with date because of inaccuracies encountered in extrapolating the quadratic curve

Several factors contribute to the suitability of a hybrid for use in a total corn harvesting system, however, grain yield, refuse yield and the grain-refuse moisture content relationship were considered the most important factors. Consequently, the equation included a term for each of the three main variables and also a constant which weighed each term according to net income potential. The constants, though somewhat arbitrary, were calculated according to net income as follows.

The net income of corn grain was calculated by assuming a yield of 120 bushels per acre of corn worth \$1.05 per bushel and with production costs of \$90 per acre to result in a net income of \$36 per acre.

Net income for corn refuse ensilage was calculated by assuming a \$6 per ton value, \$3 per ton cost, and a yield of four tons per acre to result in a net income of \$12 per acre[1].

The grain-refuse moisture content relationship involved more empiricism in assigning a numerical value. The approach used was based on the slope of that curve and its effect on timeliness of harvesting. In order to increase the number of available harvesting days, the manager would need to either harvest earlier and accept wetter grain or harvest later and accept drier refuse ensilage. By selecting a hybrid which inherently possessed a dry grain - wet stalk characteristic, as much as ten cents per bushel could be saved in grain drying costs. With 120 bushels per acre corn, the net saving would be \$12 per acre.

---

[1] Gay, Nelson, Ames, Iowa, Iowa State University of Science and Technology. Refuse harvesting costs. Private communication. 1969.

Thus the ratio of net income for grain to refuse to moisture relationship was 36: 12: 12 or 3: 1: 1. The constants in the relative rating equation were assigned according to that ratio.

Empiricism was justified in this equation by the fact that all hybrids received equal treatments and they were only compared with hybrids within the same design. More accurate constants can be calculated when better data are collected for timeliness and refuse value, but the equation for rating would still apply.

The relative ratings for the five hybrids evaluated are listed in Table 28.

Table 28. Comparison of five hybrids for suitability in a total corn harvesting system

Hybrid	Adjusted grain yield bushels/acre[a]	Refuse yield tons/acre[b]	Moisture content regression coefficient[c]	Relative rating
1	149.13	2.61	1.33	4.59
2	146.58	3.41	1.17	4.90
3	144.58	3.00	1.35	4.62
4	162.02	2.90	0.93	5.27
5	148.55	3.31	1.46	4.74
		3.05 avg.		

[a]Bushels of 15.5 percent moisture corn, wet basis

[b]Tons of dry matter per acre

[c]Slope of the regression of refuse moisture on grain moisture content (Figure 47)

Hybrid 4 exhibited the highest relative rating and was considered best suited to a total harvesting system. The high rating for this hybrid resulted from the large yield of grain and the small moisture regression coefficient. Hybrid 2 had the second highest relative rating which resulted from a large yield of refuse and a small moisture coefficient.

This analysis detected a wide range of variability between common corn hybrids in their suitability to a total harvesting system. Testing and selecting a hybrid based on its relative rating could significantly increase the feasibility of total harvesting. Such a hybrid would increase the length of the harvesting period and would improve the quality of the collected products.

The procedure outlined for determining the relative rating was correct, but complications arise when results from different experiments are compared. If one or two of the same hybrids were planted as a control group in each experiment, it would give a basis for comparison.

The measured moisture contents and yield data are tabulated in Appendix A.

SUMMARY

Pioneer farmers were accustomed to utilizing the entire corn plant, so early attempts to mechanize the harvest of corn involved the design of total harvesters so as not to depart from the cultural practices of the day. However, due to the high power requirement, high labor demand, volume of material, and problems associated with drying and storing wet corn, the development of successful total harvesting machinery was delayed until the middle of the 20th century.

The rebirth of interest in total harvesting at the present time is predicated on several factors. Expanding demands for beef, coupled with shifts in regional production levels, indicate that the midwestern states will need to maintain more beef cows in the future. Shrinkage, shipping fever, transportation costs, diminishing calf supplies due to increased buying competition, and a fluctuating supply of calves have caused the feeder calf deficit areas of the Midwest to re-evaluate the beef cow enterprise.

Corn refuse, when properly supplemented, provided a satisfactory maintenance ration for beef cows. Refuse presently is available from over 55 million acres in the United States and from 9.7 million acres in Iowa alone. Slight changes in price-cost relationships and the development of total corn harvesting machinery could make the cow calf herd a competitive enterprise for the Midwest.

A system analysis of total corn harvesting indicated that if adequate labor were available, refuse retrieval for beef cow maintenance would contribute to

the net income of the farm. By selecting "dry grain - green stalk" hybrids, the total harvesting season could be increased and the premium on fall labor would be reduced.

The feasibility of refuse retrieval depends in part on the development of efficient and economical machinery to harvest, handle, and feed the refuse ensilage. A two-row total harvester was developed by building a snapping-shelling attachment to mount between the row crop head and the chopping cylinder of a conventional forage harvester. This machine successfully harvested the entire corn plant and separated it into grain and stalk components.

Increased demands for beef, shifts in regional production patterns, development of efficient refuse retrieval machinery, and changes in price - cost relationships could make total corn harvesting and beef cows compatible and profitable enterprises in the Midwest.

CONCLUSIONS

1. Price - cost relationships and beef production trends indicate that the utility of total corn harvesting will continue to increase.
2. A system analysis indicated that beef cows could be a competitive enterprise on midwestern farms if they were maintained on corn refuse ensilage and if enough labor were available in the fall to harvest the refuse.
3. The Beefmaker II successfully harvested the entire corn plant and separated it into grain and forage components.
4. Shelled corn losses on the ground, shelled corn in the refuse, failure of the vertical auger to convey ear corn, and trash in the shelled corn are problems of the Beefmaker II which require modifications.
5. Corn grain moisture content decreased quadratically with time.
6. Corn refuse moisture content decreased linearily with time.
7. The natural drying rates of corn grain and refuse varied significantly for different hybrids with equal treatments and indicated that some common hybrids possess a "dry grain - green stalk" characteristic which suits them to a total harvesting system.
8. Hybrids can be compared for suitability in a total corn harvesting system by the application of an empirical equation developed for that purpose.

SUGGESTIONS FOR FUTURE WORK

Research needs to be conducted in several areas related to the total corn harvesting concept in order to more accurately evaluate its worth.

A thorough system analysis including several total harvesting systems and a variety of beef cow maintenance rations needs to be compiled. Current total harvesters need to be field tested and compared, and machine performance characteristics should be measured in order to formulate better coefficients for the system analysis. Refuse losses in storage, value of the refuse product, cost of retrieving refuse, and the effect of timeliness of total harvesting need to be evaluated to provide objective coefficients for the analysis. It is recommended that specific farming situations be analyzed to obtain more meaningful results.

Feeding trials to appraise the value of refuse ensilage for maintaining beef cows should be continued to substantiate the results of previous tests.

Moisture content and yield data should be collected for several corn hybrids in order to determine their relative rating for a total harvesting system.

Several feasible methods of total harvesting are currently available, but in view of the diversity in cattle raising operations, other feasible machines and methods need to be developed and compared for several operations.

Some modifications are needed to improve the performance of the Beefmaker II. The vertical auger used to elevate ear corn should be replaced with a flight or bucket conveyor. The chopper feed rolls should be enclosed with sheet metal to reduce shelled corn losses on the ground, and new snapping rolls should be designed to reduce the amount of shelled corn mixed with the refuse. A fan or cleaning system could be added to the cage sheller to clean the shelled corn so it could be artificially dried. The angle of the sheller discharge gravity flow chute should be increased, or a beater paddle should be installed to prevent plugging. If problems are encountered when gathering lodged corn, a powered feeder roll could be installed above the beater paddle to improve the gathering performance.

REFERENCES

1. Albert, W. W., Cox, D. L., and Hatfield, E. E. Stalkage ensiled with urea or biuret for wintering beef cows (R56). University of Illinois Beef Cattle Day, April 13, 1967: 29-30. 1967.

2. Aldrich, S. R. and Leng, E. R. Modern corn production. Cincinnati, Ohio, F. and W. Publishing Corporation. 1965.

3. American Society of Agricultural Engineers. Farm machinery costs and use. Agricultural Engineers Yearbook 1968. St. Joseph, Michigan, Author. 1968.

4. Beefmaker combines grain, chop stalks for silo. Beef 4, No. 9: 38-39. May, 1968.

5. Beneke, R. R. Linear programming applications to farm planning. Ames, Iowa, Iowa State University Press. 1968.

6. Burroughs, W., Culbertson, C. C., Barnes, K., and Jacobs, R. Wintering beef cows on cornstalk silage. Iowa State University of Science and Technology Agricultural Extension Service Animal Husbandry Leaflet 203. 1955.

7. Burroughs, W., Jacobson, N., Voelker, D., McWilliams, R. M., and Zmolek, W. Stretch hay supplies with ground corncobs and chopped cornstalks. Iowa State University of Science and Technology Cooperative Extension Service Pamphlet 232. 1962.

8. Case, J. I. Corn harvester: operator's instruction manual on models 210 and 220 field forage harvesters. Racine, Wisconsin, Author. 1957.

9. Davidson, J. B. and Collins, E. V. The harvesting of corn stalks. American Society of Agricultural Engineers Journal 9, No. 9: 301-302. 1928.

10. Deering, Rollie E. Bill Curry's shucklage system. The Farm Quarterly 22, No. 1: 102-107. 1967.

11. Enfield, E. Indian corn; its value, culture, and uses. New York, N. Y., D. Appleton and Company. 1866.

12. Farm equipment production. Implement and Tractor 83, No. 24: 32. 1968.

13. Ferlemann, E. F. Total corn harvest: a combine attachment for shelled corn and silage. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1966.

14. Gay, Nelson and Zmolek, William G. The beef cow herd in Iowa herd management and nutrition. Iowa State University of Science and Technology Cooperative Extension Service Pamphlet 367. 1967.

15. Hartley, C. D. Harvesting and storing corn. U.S. Department of Agriculture Farmer's Bulletin 313. 1907.

16. Herrick, J. B. and Bristol, R. F. Reducing cattle stress during shipment. Iowa Farm Science 23, No. 4: 299-301. October, 1968.

17. Herum, F. L. Comparison of corn harvesting methods. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1954.

18. Hoglund, C. R. Economic considerations in selecting silage storage and feeding systems. Michigan State University Department of Agricultural Economics Report 84. 1967.

19. Hull, D. O., Hull, A. D., and Caldwell, M. G. 1969 farm machinery operating costs. Iowa Farm Science 23, No. 7: 369-373. January, 1969.

20. Hurlbut, L. W. More efficient corn harvesting. American Society of Agricultural Engineers Journal 36, No. 12: 791-792. 1955.

21. Iowa Crop and Livestock Reporting Service. Annual crop summary - 1968. Iowa Department of Agriculture Division of Agricultural Statistics. December, 1968.

22. Iowa Crop and Livestock Reporting Service. Calf crop 1967. Iowa Department of Agriculture Division of Agricultural Statistics. 1968.

23. Iowa Crop and Livestock Reporting Service. Iowa annual farm census 1967. Iowa Department of Agricultural Statistics Bulletin 92-AL. 1967.

24. Iowa Crop and Livestock Reporting Service. Livestock movement into Iowa 1934-1966. Iowa Department of Agriculture Division of Agricultural Statistics. March, 1967.

25. Jackson, R. History of corn harvesting machinery. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1950.

26. Jacobs, R. E. Low quality roughage rations for wintering beef cattle. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1955.

27. James, S. C., ed. Midwest farm planning manual. 2nd ed. Ames, Iowa, Iowa State University Press. 1968.

28. Johnson, R. G. and Nodland, T. R. Labor used in cattle feeding. University of Minnesota Agricultural Experiment Station Bulletin 451. 1960.

29. Johnson, W. H. and Lamp, B. J. Principles, equipment and systems for corn harvesting. Wooster, Ohio, Agricultural Consulting Associates, Incorporated. 1966.

30. Jones, Phil B. How to store silage. Successful Farming 65, No. 8: 36-37. August, 1967.

31. Keller, A. H. A corn picker with stalk shredder. American Society of Agricultural Engineers Journal 31, No. 10: 512. 1950.

32. Malena, Dave. Big shift in cattle feeding - what it means to you. Successful Farming 66, No. 10: 32-33. October, 1968.

33. Market statistics number. Implement and Tractor 83, No. 24: 31-60. November, 1968.

34. Meiske, J. C. and Goodrich, R. D. Drylot vs conventional cow-calf production. Minnesota Agricultural Extension Service Research Report B-118. 1968.

35. Momotenko, N. Agricultural mechanization, the mechanization of maize harvesting for grain. United Nations Economic Commission for Europe 37. 1968.

36. Morrison, F. B. Feeds and feeding, abridged. Clinton, Iowa, Morrison Publishing Company. 1961.

37. Muller, L. D., Colenbrander, U. F., Noller, C. H., and Lane, G. T. Feeding value and fermentation characteristics of corn stalk silage (abstract). Journal of Animal Science 26: 1491. 1967.

38. Newlin, O. Water loss from grain and associated plant parts of corn after physiological maturity. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1956.

39. Richardson, Len. Cows on cornstalks. Big Farmer 40, No. 1: 82-83. 1968.

40. Rosenthal announces field-husker-shredder. Implement and Tractor 66, No. 22: 42. 1951.

41. Schroeder, Kenneth R. The design and analysis of a total corn harvester. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

42. Snedecor, G. W. and Cochran, W. G. Statistical methods. 6th ed. Ames, Iowa, Iowa State University Press. 1967.

43. Sollenberger, George. Make winter-cut corn silage. The Furrow 73: 13. March, 1968.

44. Stoecker, Arthur L. Forage systems on the Taylor County test farm. Unpublished Master of Science thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

45. Stoneberg, E. G., Schaller, F. W., Hull, D. O., Meyer, V. M., Wardle, N. J., Gay, N., Voelker, D. E. Silage production and use. Iowa State University of Science and Technology Cooperative Extension Service Pamphlet PM-417. 1968.

46. Taylor, R. E. An Iowa philosophy of beef production. Iowa State University of Science and Technology Cooperative Extension Service Pamphlet PM-333. 1966.

47. Thompson, L. M. Iowa agriculture, world food needs and educational response. Ames, Iowa, Center for Agricultural and Economic Development, Iowa State University of Science and Technology. 1965.

48. Tracy, S. M. and Lloyd, E. R. Corn. Mississippi Agricultural Experiment Station Bulletin 33. 1895.

49. U.S. Agricultural Marketing Service. Cattle and calves on feed, 1955-1959. U.S. Department of Agriculture Statistical Bulletin 277. 1961.

50. U.S. Agricultural Marketing Service. Livestock and meat statistics, 1957. U.S. Department of Agriculture Statistical Bulletin 230. 1958.

51. U.S. Agricultural Marketing Service. Livestock and meat statistics, 1962. U.S. Department of Agriculture Statistical Bulletin 333. 1963.

52. U.S. Agricultural Marketing Service. Livestock and poultry inventory, January 1, 1940-1954. U.S. Department of Agriculture Statistical Bulletin 177. 1956.

53. U.S. Agricultural Research Service. Losses in agriculture. U.S. Department of Agriculture Handbook No. 291. 1965.

54. U.S. Agricultural Statistical Reporting Service. Cattle and calves and sheep and lambs on feed, 1959-1965. U.S. Department of Agriculture Statistical Bulletin 387. 1967.

55. U.S. Agricultural Statistical Reporting Service. Livestock and poultry inventory, January 1, 1961-1965. U.S. Department of Agriculture Statistical Bulletin 389. 1967.

56. U.S. Agricultural Statistical Reporting Service. Livestock and poultry inventory, January 1, 1968. 1968.

57. U.S. Agricultural Statistical Reporting Service. Livestock and poultry inventory, January 1, 1969. 1969.

58. U.S. Agricultural Statistical Reporting Service. Number of cattle feedlots by size groups and number of fed cattle marketed, 1962-1967. 1968.

59. U.S. Department of Agriculture Economic Research Service. Farm machinery and equipment. Number and value of shipments for domestic use. 1935-39 to 1966. U.S. Department of Agriculture Statistical Bulletin 419. 1968.

60. U.S. Department of Agriculture Economic Research Service. Handbook of agricultural charts 1967. U.S. Department of Agriculture Handbook No. 348. 1967.

61. Vetter, R. L. and Buchele, W. F. Preliminary comparison of feeding value of corn plant by-product materials for beef cows. Iowa State University of Science and Technology Cooperative Extension Service Leaflet R109. 1968.

62. Ways to save crop residue. Successful Farming 66, No. 7: 48D. July 1968.

63. What does it cost to grow corn. International Harvester Farm 52, No. 2: 8. Spring, 1969.

64. Yaw, W. H. Corn belt farming next ten years. Unpublished mimeographed paper presented at Illinois Cattle Feeders Association Meeting, Dekalb, Illinois, December, 1968. Galesburg, Illinois, The Farm Clinic. ca. 1968.

65. Zimmerman, Mark. Don't blame it all on the combine. Implement and Tractor 83, No. 10: 22-26. April, 1968.

66. Zimmerman, Mark. Why not harvest all the corn plant. Implement and Tractor 83, No. 14: 26-28. June, 1968.

67. Zintheo, C. J. Corn harvesting machinery. U.S. Department of Agriculture Office of Experiment Station Bulletin 173. 1907.

68. Zmolek, W. G. Beef outlook . . . growing consumer demand points to increased production. Iowa Farm Science 22, No. 7: 32-33. January, 1968.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to his major professor, Dr. Stephen J. Marley, for his guidance and help during this research endeavor.

Appreciation is also expressed to Dr. Clarence W. Bockhop and Dr. Raymond R. Beneke who served on the graduate committee.

The author acknowledges the suggestions and encouragement of Dr. Wesley F. Buchele during the early stages of the research.

Appreciation is extended to the John Deere Des Moines Works, John Deere Ottumwa Works, John Deere Harvester Works, Dole Valve Company, Avco New Idea Company, and Union Iron Works for their generous support of the research project through funds and equipment.

Acknowledgment is made to Clarence Johnson for his help with the photography and to George Ayres for his suggestions and help with the field tests.

Acknowledgment is also made to Bob Fish, Jim Anderson, Rex Whitcanack, and Orvil Rutzen for their ideas and assistance with the machine construction.

Appreciation is expressed to the author's colleague, Dave Gustafson, for his ideas and help with the research.

Finally, the author is grateful to his wife, Margaret, for her understanding and encouragement throughout the research endeavor.

APPENDIX A: CORN YIELD AND MOISTURE CONTENT DATA

Table 29. Measured corn grain moisture content for different sampling dates for five hybrids

	Coded date[a]	Percentage grain moisture content, wet basis				
		E	m	L	L	m
		TXS102 Hybrid 1	3570 Hybrid 2	3545 Hybrid 3	3505 Hybrid 4	3369 Hybrid 5
	1	34.3	40.0	41.0	42.4	38.2
	1	33.8	37.8	39.6	43.3	40.6
Sept. 18	1	36.5	38.0	40.3	42.7	39.2
	1	35.8	37.7	43.3	47.0	41.2
	1	36.2	39.9	40.8	42.7	39.9
		176.6 35.3	193.4 38.7	205.0 41.0	218.1 43.6	199.1 37.8
	2	31.8	36.7	--[b]	--	--
	2	30.7	34.6	--	--	--
Sept. 25	2	33.4	32.8	--	--	--
	2	32.7	33.7	--	--	--
	2	31.1	35.1	--	--	--
		159.7 31.9	172.9 34.6			
	3	27.8	30.4	33.5	34.6	30.9
	3	27.5	30.8	31.2	34.2	30.4
Oct. 2	3	27.9	28.5	31.2	33.4	29.3
	3	28.1	29.9	38.1	33.7	32.1
	3	25.1	32.5	30.3	34.3	30.5
		136.4 27.3	152.1 30.4	164.3 32.9	170.2 34.0	153.2 30.6

[a]Date 1 was September 18, 2 was September 25, 3 was October 2, 5 was October 16, 6 was October 23, and 7 was October 29, 1968

[b]A sample was not collected

Table 29. (continued)

Coded date[a]	Hybrid 1		Hybrid 2		Hybrid 3		Hybrid 4		Hybrid 5	
	Percentage grain moisture content, wet basis									
5	22.2		27.2		23.4		26.9		24.3	
5	22.5		26.3		24.2		27.1		23.1	
Oct. 16 5	24.8		22.4		28.9		27.3		24.7	
5	22.5		23.2		26.4		26.5		24.8	
5	20.5		24.4		22.6		30.2		23.8	
	112.5	22.5	123.5	24.7	125.5	25.1	138.0	27.2	120.7	24.1
6	--[b]		--		20.0		24.3		20.3	
6	--		--		20.9		23.8		19.8	
Oct. 23 6	--		--		21.6		24.2		22.8	
6	--		--		24.3		25.8		21.1	
6	--		--		22.9		24.6		20.9	
					109.7	21.9	122.7	24.5	104.9	21.0
7	17.7		18.9		24.5		21.2		18.2	
7	15.8		21.8		19.0		24.5		20.2	
Oct. 29 7	20.4		20.1		18.6		23.3		20.0	
7	17.5		19.5		18.5		22.8		19.4	
7	18.3		20.7		19.3		22.6		18.6	
	89.7	17.9	101.0	20.2	99.9	20.0	114.4	22.9	96.4	19.3

Table 30. Measured corn refuse moisture content for different sampling dates for five hybrids

	Coded date[a]	Percentage refuse moisture content, wet basis				
		Hybrid 1	Hybrid 2	Hybrid 3	Hybrid 4	Hybrid 5
	1	66.9	75.1	72.8	74.8	75.3
	1	65.7	73.2	71.5	73.9	74.7
	1	67.4	72.9	71.8	74.9	74.4
Sept. 18	1	66.8	72.1	76.5	74.9	74.4
	1	69.2	74.2	69.7	73.1	75.5
		336.0 66.0	367.5 73.5	362.3 72.5	371.6 74.3	374.3 74.9
	2	63.2	67.4	--[b]	--	--
	2	62.0	67.8	--	--	--
Sept. 25	2	62.3	62.7	--	--	--
	2	62.8	63.4	--	--	--
	2	65.4	64.3	--	--	--
		315.7 63.1	325.6 65.1			
	3	58.8	63.0	57.3	66.0	63.8
	3	59.5	60.0	58.4	62.5	60.7
Oct. 2	3	63.6	61.1	62.1	65.5	64.0
	3	60.5	60.8	65.8	64.8	64.8
	3	57.0	64.5	62.1	65.8	63.0
		299.4 59.9	309.4 61.9	305.7 61.1	324.6 64.9	316.3 63.3

[a]Date 1 was September 18, 2 was September 25, 3 was October 2, 5 was October 16, 6 was October 23, 7 was October 29, 1968

[b]A sample was not collected for this hybrid

Table 30. (continued)

	Coded date[a]	Percentage refuse moisture content, wet basis				
		Hybrid 1	Hybrid 2	Hybrid 3	Hybrid 4	Hybrid 5
	5	56.0	61.8	53.3	62.8	56.2
	5	64.4	58.0	54.9	65.2	50.6
	5	60.3	55.8	61.9	65.6	52.7
Oct. 16	5	54.8	55.1	55.8	62.9	57.5
	5	48.0	57.9	47.3	65.7	53.8
		283.5 56.7	288.6 57.5	273.2 54.6	322.2 64.4	270.8 54.2
	6	--[b]	--	50.9	53.7	49.7
	6	--	--	43.4	50.9	47.4
Oct. 23	6	--	--	37.8	53.2	50.4
	6	--	--	46.1	57.0	46.1
	6	--	--	45.8	54.3	44.9
				224.0 44.8	269.1 53.8	238.5 47.5
	7	39.8	49.1	47.6	55.6	41.1
	7	43.4	42.3	54.2	64.9	42.4
Oct. 29	7	40.4	54.0	36.8	59.8	45.3
	7	35.1	46.6	36.5	48.8	42.3
	7	45.5	54.1	39.9	45.7	49.7
		204.2 40.8	246.1 49.2	215.0 43.0	274.8 55.0	210.8 42.2

Table 31. Yield of grain and refuse for five hybrids of corn

Replication	Hybrid	Grain yield bushels/acre @ 15.5%	Refuse yield, tons/acre Dry weight	Wet weight
III	4	156.23 19	3.26	7.34
II	1	147.11 13	2.50	4.16
IV	3	146.59 12	2.25	4.30
III	3	167.25 23	2.64	5.76
II	3	163.06 21	3.85	6.10
I	1	133.21 3	2.43	4.30
I	5	149.58 15	3.61	6.12
V	3	165.77 22	2.99	4.71
II	2	155.79 18	3.50	6.88
I	4	145.81 10	2.33	6.64
II	4	161.53 20	2.58	6.42
I	2	126.93 1	3.42	5.92
IV	1	137.38 6	2.78	4.67
IV	5	132.80 2	3.36	6.20
II	5	151.22 16	3.15	5.76
I	3	188.19 25	3.29	5.47
IV	4	153.06 17	3.21	6.27
V	5	143.24 8	3.58	6.20

Table 31. (continued)

Replication	Hybrid	Grain yield bushels/acre @ 15.5%	Refuse yield, tons/acre Dry weight	Refuse yield, tons/acre Wet weight
III	1	137.30 5	2.39	3.67
III	5	138.81 7	2.86	5.69
V	2	145.28 9	3.32	7.22
III	2	137.28 4	3.78	7.07
V	4	176.52 24	3.13	5.76
V	1	148.55 14	2.94	5.40
IV	2	145.82 11	3.01	6.56
		Average	Average	Average
	1	140.71	2.61	4.44
	2	142.22	3.41	6.73
	3	166.17	3.00	5.27
	4	158.63	2.91	6.49
	5	143.13	3.31	5.99

APPENDIX B: SURVEY OF PUBLIC OPINION CONCERNING TOTAL CORN HARVESTING

Beefmaker II was displayed at the 1969 Iowa Retail Farm and Power Equipment Association Show in Des Moines, Iowa, from February 18 to February 20, 1969. The following opinions were solicited at that show to monitor public reaction to total corn harvesting. The results were biased because the more progressive managers are more apt to attend the show, people were reluctant to fill out the questionnaire and those who did were already interested in the concept, and a specific machine was on display. Approximately 15,000 to 20,000 people attended the show, but very few were motivated to fill out a questionnaire.

Total number questionnaires completed - 92

Farmers	79
Dealers	7
Other	6

Total acres	43,682
Average acres	474.8
Range of acres	0 - 2,000
Total beef cows	4,115
Average beef cows	44.7
Range of beef cows	0 - 400

Number reporting per range:

	Number reporting	% of total reporting
1 - 200 acres	8	9%
201 - 600 acres	49	53%
Over 600 acres	22	24% (11% over 1000 Ac.)
Total number with land	79	86%

1 - 25 cows	6		7%	
26 - 75 cows	28		30%	
Over 75 cows	19		21%	
Total number with cows	53		58%	

	Farmers	Dealers	Others	Total
My personal interest in total corn harvesting is:				
High	61%	57%	17%	58%
Moderate	34%	14%	83%	36%
Low	5%	14%	0%	5%
No interest	0%	14%	0%	1%
In my opinion, general interest in total corn harvesting is:				
High	43%	14%	17%	39%
Moderate	52%	43%	66%	52%
Low	4%	29%	17%	7%
No answer	1%	14%	0%	1%
My preference for a basic power unit is:				
S. P. combine	14%	29%	14%	15%
S. P. forage harvester	20%	14%	14%	20%
Pulled forage harvester	55%	14%	57%	52%
Mounted corn picker	8%	14%	0%	8%
Other	0%	14%	15%	2%
No answer	3%	15%	0%	3%
I would invest this amount for a total corn harvester:				
Over $12,000	9%	0%	0%	8%
8,000 - 12,000	11%	43%	17%	14%
4,000 - 8,000	34%	14%	17%	32%
2,000 - 4,000	24%	14%	33%	24%
Less than 2,000	5%	0%	0%	4%
No answer	17%	29%	33%	18%

	Farmers	Dealers	Others	Total
I want a machine to collect:				
Ear corn and stover	10%	0%	14%	9%
Gr. ear corn and stover	7%	0%	14%	7%
Shelled corn and stover	40%	43%	14%	39%
Choice of ear corn or shelled corn plus stover	35%	29%	43%	35%
No answer	8%	28%	15%	10%
I would buy a new forage harvester if a snapping attachment were available:				
Yes	60%	14%	67%	57%
No	18%	14%	17%	17%
No answer	22%	72%	16%	26%